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# Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors

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**Aims** While patient history taking and physical examination remain the cornerstones of patient evaluation in clinical practice, there has been a decline in the accuracy of the latter. Pocket-size hand-held echocardiographic (PHHE) devices have recently been introduced and could potentially improve the diagnostic accuracy of both medical students and junior doctors. The amount of training required to achieve optimal results remains a matter of debate. We hypothesized that the use of PHHE after limited training in the form of a tutorial can improve the clinical diagnosis even in the hands of medical students and inexperienced physicians.

**Methods and results** Five final-year medical students and three junior doctors without prior echocardiographic experience participated in a standardized 2 h PHHE bedside tutorial. Subsequently, they assessed 122 cardiology patients using history, physical examination, ECG and PHHE. Their final clinical diagnosis was compared against that of a consultant clinician's and also expert in echocardiography. A total of 122 PHHE were performed of which 64 (53%) by final-year medical students and 58 (47%) by junior doctors. Mean $\pm$ SD for diagnostic accuracy after history, physical examination, and ECG interpretation was $0.49 \pm 0.22$ (maximum = 1), whereas the addition of PHHE increased its value to $0.75 \pm 0.28$ ($Z = -7.761$, $P < 0.001$). When assessing left ventricular systolic dysfunction by means of history and physical examination, specificity was 84.9% and sensitivity only 25.9%, whereas after including findings from PHHE, these figures rose to 93.6 and 74.1%, respectively.

**Conclusion** The use of PHHE after brief bedside training in the form of a tutorial greatly improved the clinical diagnosis of medical students and junior doctors, over and above history, physical examination, and ECG findings.

**Keywords** Hand-held echocardiography • Pocket-size • Students • Junior doctors • Diagnostic accuracy



## Introduction

Patient history taking and physical examination remain the backbone of the evaluation of a patient in daily clinical practice. However, physical examination skills may be variable and medical students misidentify up to 80% of cardiac sounds.[1,2] Pocket-size, hand-held echocardiographic (PHHE) devices have recently been introduced to add to the existing wide range of ultrasound imaging devices but the precise utility of those remains to be defined. Current PHHE devices are equipped with diagnostic quality two-dimensional (2D) and colour Doppler imaging rendering them useful for the qualitative evaluation of right and left ventricular (LV) function, valvular abnormalities, LV hypertrophy (LVH), pericardial effusion, and aortic root size at bedside in capable hands.[3]

To date, there have been few studies assessing the utility of PHHE in a variety of clinical settings and in the hands of operators with variable experience (medical residents, cardiology fellows, accredited echocardiographers).[4,5] Even though most of these studies show an improvement of diagnostic accuracy, the additive value of PHHE to history and physical examination and additional prognostic information from the PHHE use[6] is lacking. The training

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time in these studies varies from as short as 3 h in the Duke limited echo assessment project (LEAP)[7] to as long as 5 days in a study by Croft on junior medical residents.[8] A small study on 10 students evaluating 12 standardized patients initially with physical examination alone and after a 10-day training course with PHHE confirmed poor physical examination skills and showed an improvement in diagnostic accuracy with the use of PHHE.[9] The recent European Association of Echocardiography recommendations on the use of PHHE devices[10] propose that for non-accredited echocardiographers, a dedicated training time should be mandatory, without, however, clarifying length or specifications. To date, no large studies have evaluated in a comprehensive manner the added value of PHHE use after a brief tutorial to the final diagnosis made by medical students and junior doctors.

The present study was undertaken in a sample of final-year medical students and junior doctors who received a 2-h bedside tutorial on echocardiography to assess:

(i) the incremental value to clinical diagnosis using PHHE over history, physical examination and ECG interpretation;
(ii) sensitivity, specificity, positive and negative predictive values (PPV and NPV) of PHHE for the diagnosis of basic cardiac findings such as left and right ventricular function, valvular abnormalities, pericardial effusion, LVH and aortic root dilatation in a binary fashion.

The aim of this study was therefore to examine whether students and/or junior doctors were able to improve on their clinical diagnosis with the additional aid of PHHE over and above clinical examination and ECG findings. The aim was not to compare the quality and findings of PHHE against the standard echocardiography *per se*.

# Methods

The PHHE used was the V-Scan (GE Vingmed Ultrasound AS, Horten, Norway). This ultrasound device consists of a display unit (135 × 73 × 28 mm) connected to a broadband width phased-array probe (1.7–3.8 MHz; 120 × 33 × 26 mm). Its total weight (unit and probe) is 390 g. The total possible scanning time is 1 h with a fully charged battery. This platform provides 2D and colour Doppler echocardiographic images on a 3.5-inch screen (resolution, 240 × 320 pixels). There are a limited number of controls, including those for adjusting imaging depth and gain. Images can be frozen and scrolled for review. An electronic calliper and touchpad allow distance measurements to be performed. Data are stored on micro-SD or micro-SDHC cards. Data may be stored in examination folders, and all data can be recalled using a gallery function and downloaded into any conventional computer.

In this prospective study, five final-year medical students from Imperial College London (who had completed their cardiology rotation) and three junior doctors [Foundation Year 1 (equivalent to first year resident) and ST1 level (equivalent to 3rd year resident)] without prior echocardiographic experience participated in a standardized 2 h PHHE training programme. The programme for two trainees at a time consisted of a 10 min bedside tutorial on ultrasound (basic principles of 2D and colour Doppler imaging) and the PHHE device, 20 min of case reviews [starting with normal anatomy and subsequently moving onto cases with LV systolic dysfunction, mild-to-severe pulmonary hypertension (dilated, impaired right ventricle (RV) and severe tricuspid regurgitation), aortic stenosis (AS), and regurgitation, mitral stenosis and regurgitation, pericardial effusion, dilated aortic root, and LVH], and 90 min of hands-on practise (∼10 cases) on ward patients. Three standard views were taught including the left parasternal long- and short-axis view and the apical four-chamber view. Colour Doppler interrogation was used to determine regurgitant valvular lesions but no pulsed or continuous wave Doppler or M mode was employed (these features are lacking in the PHHE system).

Between October 2011 and February 2012, a total of 122 patients from the Cardiology ward and the Emergency Department of Hammersmith Hospital, Imperial College Healthcare NHS Trust, London, UK, agreed to participate in the present study. The research protocol was approved by the locally appointed ethics committee and informed consent was obtained from all participants. The protocol included a 20 min face-to-face interview with the patient, divided into 5 min history taking, 5 min physical examination, 2 min ECG interpretation, and 8 min scanning and simultaneous clip storing using the PHHE device. Each patient was assessed once by one of the trainees, and the findings were documented using a predesigned template (see Supplementary data online, Table S1).

During history taking, trainees were only allowed to explore the presenting complaint. The attending cardiologist, who was fully aware of the patient's clinical condition, had a brief conversation with the patient prior to the consultation in order to ensure that no past medical or drug history was revealed during the student's examination.

Standardized cardiovascular examination similar to those required for the final years' clinical examination (PACES) included inspection (jugular venous pressure, peripheral pitting oedema, ascites, peripheral stigmata of endocarditis), palpation (arterial pulse, apex, right parasternal for ventricular lift, hepatomegaly), cardiac (quality of heart sounds, added heart sounds, murmurs), and lung (crepitations, wheeze, dullness) auscultation. The attending cardiologist (consultant) also performed a full cardiovascular examination to establish the rate of misinterpretation of physical findings. The patient's ECG was subsequently reviewed and the trainee could update their provisional diagnosis thus far based on history and examination alone. The trainee's ECG interpretation was again compared with that of the cardiologist.

At the end of the PHHE study, the trainees had to comment on into six areas that were felt to be clinically important:

(i) LV systolic function, reported as good, mild (estimated visual ejection fraction, EF, 45–54%), moderate (EF 36–44%), or severely (EF ≤35%) impaired. The differences between cardiologist's and trainees' assessments were graded (positive difference indicates that the student overestimates the LV systolic function—for example, if they reported mild impairment, when it was severe, it was graded as +2). To assess sensitivity and specificity, binary variables (normal/mild vs. moderate/severe LV systolic dysfunction) were used. Wall motion abnormalities were not reported.
(ii) Right ventricular systolic function (good, mild/moderate/severely impaired).
(iii) Presence of valvular abnormalities (regurgitant or stenotic) and their grade (mild, moderate/severe). The severity of regurgitant lesions was based on 2D findings (atrial or ventricular enlargement, hyperdynamic LV) and qualitative colour-Doppler findings (width of vena contracta and jet area), whereas the severity of stenotic lesions was based on 2D findings of valve mobility, thickness, and calcification alongside chamber changes (hypertrophy in AS, atrial dilatation, or pulmonary hypertension in

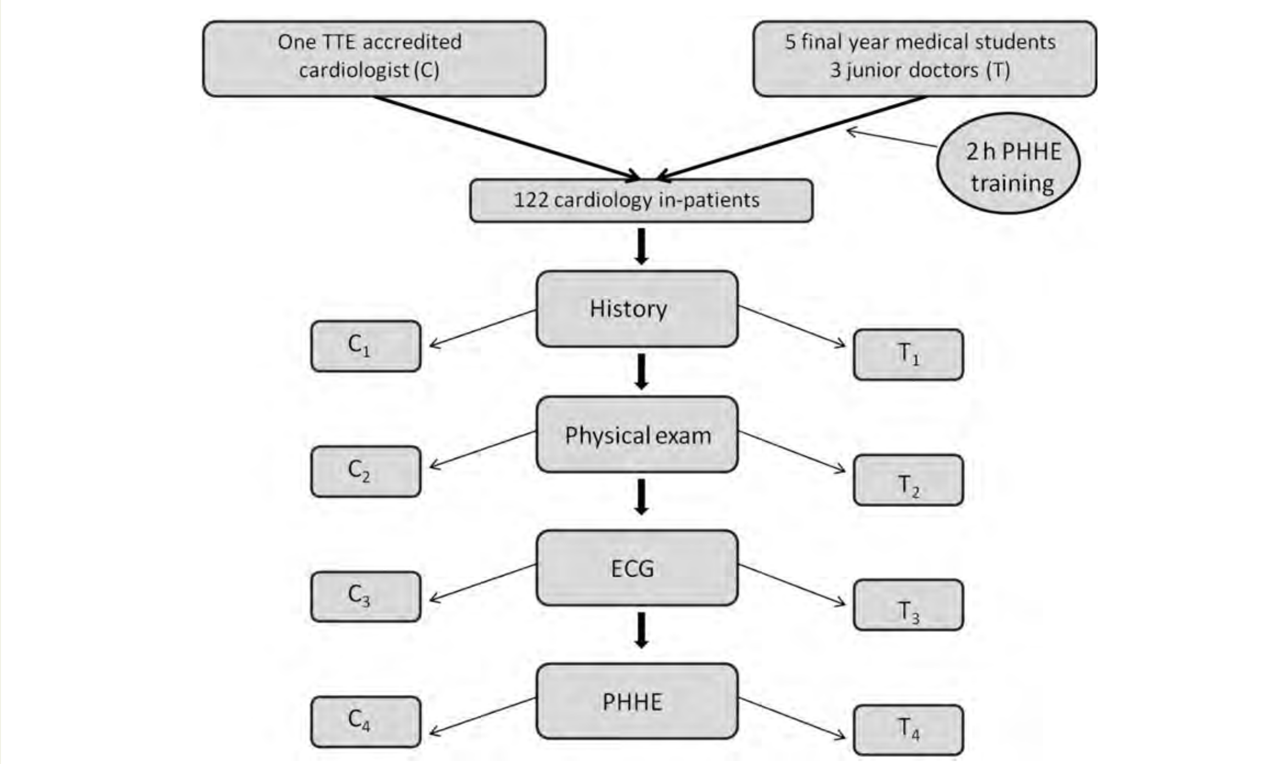


**Figure 1** Flow chart of study design. TTE, transthoracic echocardiography; PHHE, pocket-size hand-held echocardiography; C, score of cardiologist's diagnoses; T, score of trainees' diagnoses. Scoring system of diagnoses: for every true-positive salient diagnosis 1 point, for each true-positive secondary diagnosis 0.5 points, for false positive −0.5 points and for false or true negatives 0 points were allocated. For normal subjects, 1 point was allocated if normality correctly identified. Minimum score was 0.

mitral stenosis)[8] presence and grade of LVH (mild LV wall thickness 1.3–1.5 cm and moderate/severe LV wall thickness >1.6 cm).

(iv) Presence of aortic root dilatation (by measuring the aortic root at the sinuses of valsava and standardizing it for the body surface area according to the British Society of Echocardiography guidelines).

(v) Presence of pericardial effusion (mild <0.5 cm or moderate/large >0.5 cm).

Subsequently, the supervising cardiologist, accredited on transthoracic echocardiography, performed a PHHE examination to establish the echocardiographic cardiac abnormalities (reference standard). At the end of the examination, trainees' clips were reviewed and compared with the ones obtained by the cardiologist. Their image quality was judged as fair, poor, and non-diagnostic (or unable to obtain).

After each part of the examination (history, physical examination, ECG review, and PHHE), the students listed their diagnoses in a data sheet (see Supplementary data online, Table S1). The final diagnosis/diagnoses were established by the supervising cardiologist (*Figure 1*). These were split into salient (e.g. severe AS, moderate/severe LV systolic dysfunction, non-ST segment elevation acute coronary syndrome: +1 point for each one) and secondary [e.g. mild mitral regurgitation (MR), mild LVH: 0.5 points for each one]. In the end, a maximum score was allocated to each patient, depending on their number of diagnoses (*Figure 1*, $C_4$). For example, a patient with severe AS, mild MR, and moderate LV systolic dysfunction would score $(+1 + 0.5 + 1 = 2.5)$ a total of 2.5 points. Trainee findings were recorded as true positive (+1 point for salient, +0.5 for secondary), false positive (−0.5 points), and true and false negatives (0 points).[9] For patients with normal cardiovascular system, 1 point was given if a student identified normality. After each modality (history, physical examination, ECG, and PHHE) trainees' scores were summed up for each patient (*Figure 1*, T). Diagnostic accuracy was obtained by dividing the above scores with the maximum score for each patient. (*Figure 1*; e.g. $T_2/C_4$, diagnostic accuracy after history and physical examination, $T_4/C_4$ diagnostic accuracy after history, physical exam, ECG, and PHHE).

## Statistical analysis

Statistical analysis was performed by SPSS package, version 17 (SPSS Inc., Chicago, IL, USA). Data are presented as the mean ± SD, median (interquartile range), and proportions (percentages). The chi-squared test was used to calculate sensitivity, specificity, PPV and NPV. The Cohen's kappa coefficient was used to measure inter-rater agreement for categorical variables. The Wilcoxon signed-rank test (non-parametric, paired variables) was used to assess whether the incremental diagnostic accuracy after PHHE (in addition to history, physical examination, and ECG) was statistically significant. The null hypothesis was rejected at two-tailed $P < 0.05$.

# Results

## General demographics

A total of 122 PHHE were performed, of which 64 (53%) by final-year medical students and 58 (47%) by junior doctors. The mean age of the participants was 64 ± 16.1 and 87 (71.3%) were males. Out of 122 patients, 69 (56.6%) had LV systolic dysfunction (of any degree), 16 (13.1%) had any degree of RV systolic dysfunction, 74 (52.5%) had valvular abnormalities, 5 (4.1%) had prosthetic valves, 6 (4.9%) had pericardial effusions, and 4 (3.3%) had aortic root dilatation. A fair (diagnostic) quality of images was obtained by trainees in 109 (89.3%) patients (students vs. junior doctors 90.6 vs. 87.9%, $P = 0.225$), whereas 11 (7.8%) studies were of poor quality and in 2 (1.6%) trainees could not obtain any images (non-diagnostic).

## Physical examination

In 18 (14.8%) patients, trainees misinterpreted the physical signs. This percentage was higher among students (20.3%) compared to junior doctors (8.6%), even though this difference was not statistically significant ($P = 0.069$).

When assessing for moderate-to-severe LV dysfunction by means of history and physical examination trainee specificity was 84.9% and sensitivity only 25.9%. Assessment for the presence of valvular abnormality (without specifying which valve or type of abnormality) showed 93.8% specificity and 45.9% sensitivity (*Table 1*).

## Electrocardiogram

Trainees misinterpreted ECGs in 19 (15.6%) patients. Students were more prone to misinterpret ECGs compared to junior doctors (26.3 vs. 3.4%, $P < 0.001$).

## PHHE echocardiography

### LV assessment

According to trainees' assessments, there were 60 (50%) patients with normal LV systolic function, 16 (13.3%) with mild, 30 (25%) with moderate, and 14 (11.7%) with severe LV systolic function impairment. According to the cardiologist's assessments, there were 53 (43.4%) patients with normal LV systolic function, 15 (12.3%) with mild, 34 (27.9%) with moderate, and 20 (16.4%) with severe LV systolic function impairment.

In 94 (78.3%) patients, there was concordance between the cardiologist and trainees in LV assessment, in 18 (15%) trainees underestimated or overestimated LV by one grade and in 8 (6.7%) by at least two grades (*Figure 2*). The Cohen's kappa coefficient for LV systolic function between trainees and the cardiologist was 0.606 ($P < 0.001$). Sensitivity for moderate-to-severe LV impairment was 74.1% (40/54), whereas specificity was 93.6% (62/66) (*Table 2*).

### Right ventricular assessment

According to trainees' assessments, there were 112 (93.3%) patients with normal RV systolic function, 5 (4.2%) with moderate and 3 (2.5%) with severe RV systolic impairment. According to the cardiologist's assessments, 106 (86.9%) patients were classified as having normal RV, 4 (3.3%) as having mild, 8 (6.6%) moderate, and 4 (3.3%) severe RV systolic impairment.

In 112 (79.4%) patients, there was concordance between the cardiologist and trainees for RV assessment; in 4 (3.3%) patients, trainees overestimated RV by one grade; and in 4 (3.3%) by two or three grades. Cohen's kappa coefficient for RV systolic function between trainees and the cardiologist was 0.786 ($P < 0.001$). Sensitivity for moderate-to-severe RV impairment was 66.7% (8 of 12), whereas specificity 100% (108 of 108) (*Table 2*).

**Table 1** **Trainee sensitivity, specificity, PPV and NPV for LV systolic function and any valvular abnormalities identified during physical examination (reference standard: PHHE performed by a TTE-accredited cardiologist)**

| | Physical examination | |
|---|---|---|
| | Moderate/severe LV systolic function | Any moderate/severe valvular abnormality |
| Sensitivity | 25.9 | 45.9 |
| Specificity | 84.9 | 93.8 |
| PPV | 60.9 | 91.9 |
| NPV | 45.5 | 52.9 |

All figures are expressed as percentages (%). PPV, positive predictive value; NPV, negative predictive value; LV, left ventricular; PHHE, pocket-size hand-held echocardiography; TTE, transthoracic echocardiography.

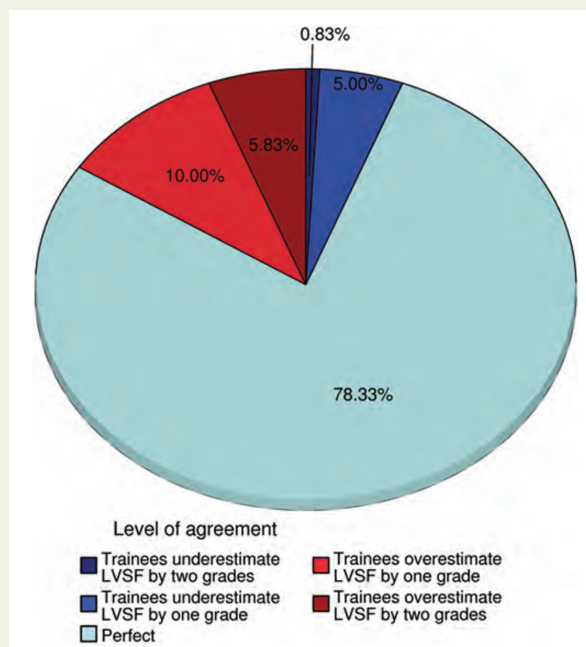


**Figure 2** Pie chart showing the agreement between trainees and the cardiologist in left ventricular systolic function (LVSF) assessment.

**Table 2** Trainee sensitivity, specificity, PPV and NPV for various echocardiographic parameters (student's PHHE vs. cardiologist's PHHE—reference standard)

| | Moderate-to-severe LV systolic dysfunction | Moderate-to-severe RV systolic dysfunction | Moderate-to-severe valvular regurgitation | Moderate-to-severe valvular stenosis | Moderate-to-severe LVH | Moderate-to-large pericardial effusion |
|---|---|---|---|---|---|---|
| Sensitivity | 74.1 | 66.7 | 70.0 | 85.7 | 66.7 | 100 |
| Specificity | 93.9 | 100 | 98.0 | 100 | 100 | 100 |
| PPV | 90.9 | 100 | 93.3 | 100 | 100 | 100 |
| NPV | 81.6 | 96.4 | 89.0 | 99.2 | 98.3 | 100 |

All figures are expressed as percentages (%). PPV, positive predictive value; NPV, negative predictive value; PHHE, pocket-size hand-held echocardiography; LV, left ventricular; RV, right ventricular; LVH, left ventricular hypertrophy.



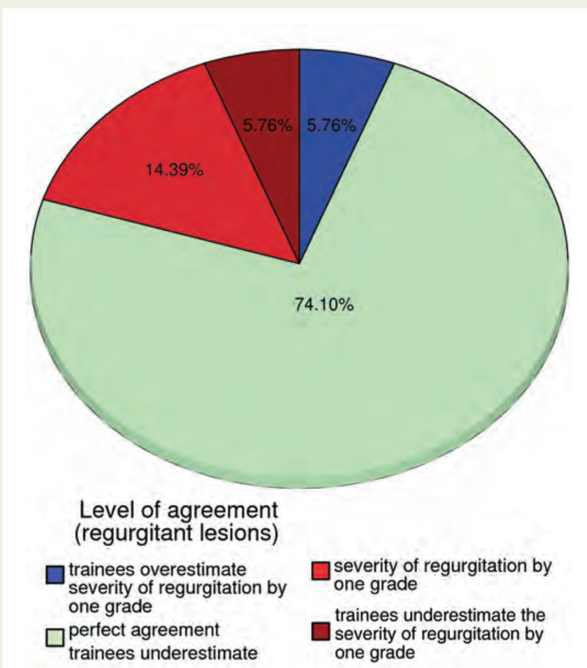


**Figure 3** Pie chart showing the agreement between trainees and the cardiologist regarding the presence and severity of regurgitant lesions.

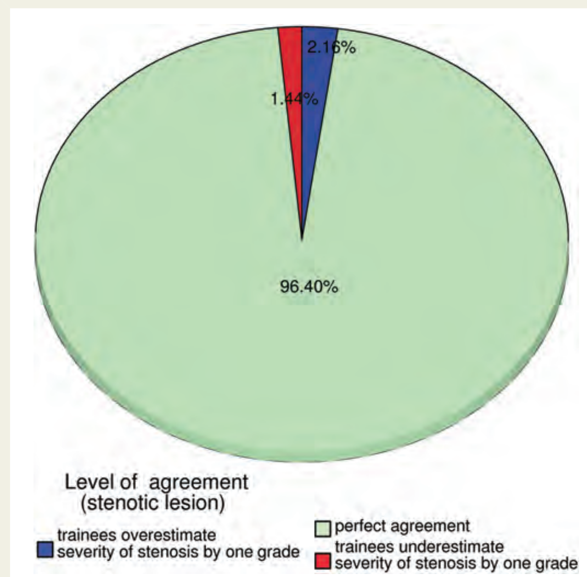


**Figure 4** Pie chart showing the agreement between trainees and the cardiologist regarding the presence and severity of stenotic valvular lesions.

### Valvular abnormalities

There were a total of 94 valvular lesions (present in 74 patients), 10 of which (10.6%) were stenotic and 84 (89.3%) regurgitant. Twenty-six were (27.7%) affecting the aortic, 54 (57.4%) the mitral, and 14 (14.9%) the tricuspid valve.

### Regurgitant lesions

According to trainees' assessments, there were 66 valvular regurgitant abnormalities identified. Of those, 36 (54.5%) were mild and 30 (45.5%) moderate to severe. According to the cardiologist's assessments, there were 84 regurgitant valvular abnormalities identified. Of those, 44 (52.4%) were classified as mild and 40 (47.6%) were moderate to severe. The level of agreement between trainees and the cardiologist in assessing regurgitant lesions is shown in *Figure 3*. The Cohen's kappa coefficient for valvular regurgitation between trainees and the cardiologist was 0.600 ($P < 0.001$).

Trainee sensitivity for detecting moderate-to-severe valvular regurgitation was 70% (28 of 40), whereas specificity was 98% (97 of 99) (*Table 2*). There were eight (20%) patients where a moderate-to-severe regurgitation was overlooked and four (10%) cases where it was thought to be mild.

### Stenotic lesions

According to trainees' assessments, there were 10 stenotic valvular abnormalities of which 4 (40%) mild and 6 (60%) moderate to severe. According to the cardiologist's assessments, there were eight stenotic valvular abnormalities of which one (12.5%) mild and seven (87.5%) moderate to severe (*Figure 4*). The Cohen's

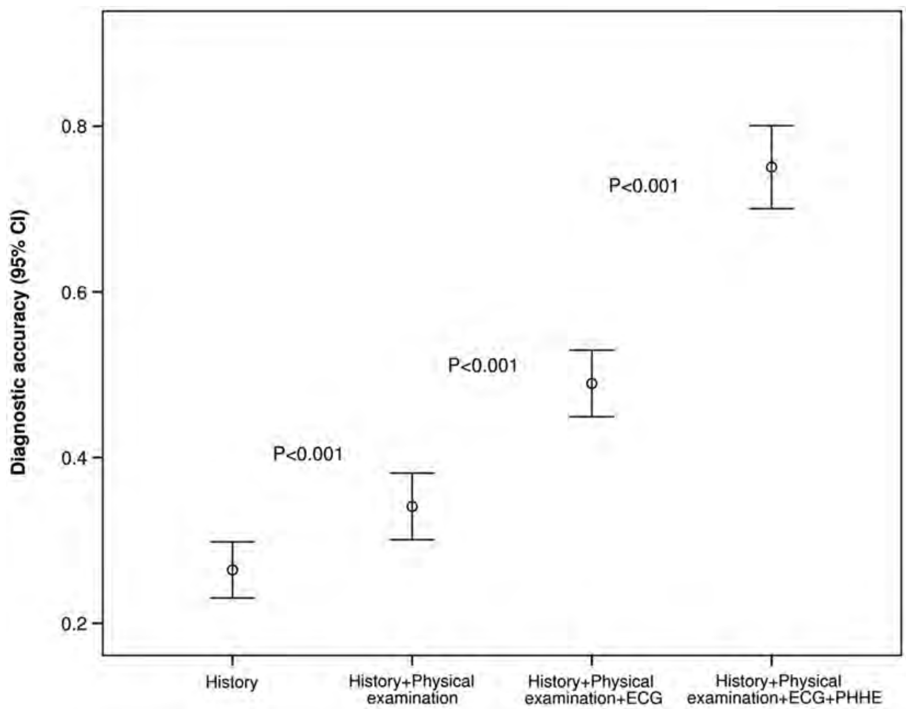


**Figure 5** Increased diagnostic accuracy (mean ± SD), in both medical students and junior doctors, with the addition of pocket-size hand-held echocardiography (PHHE) to the other examination modalities (history, physical examination and ECG reviewing). CI, confidence intervals; ECG, electrocardiogram.

kappa coefficient for valvular stenosis between trainees and the cardiologist was 0.707 ($P < 0.001$).

Trainee sensitivity to identify moderate-to-severe valvular stenosis was 85.7% (6 of 7), whereas specificity was 100% (113 of 113) (*Table 2*).

### Other echocardiographic abnormalities

According to the cardiologist's assessments, there were in total 9 patients with LVH (6 with moderate to severe), 6 patients with pericardial effusions (one with moderate to large), and 4 patients with the dilated aortic root. The Cohen's kappa coefficient for major abnormalities (including moderate-to-severe LVH, dilatation of an aortic root, and moderate-to-large pericardial effusion) between trainees and the cardiologist was 0.891 ($P < 0.001$). Nine of 11 (sensitivity 81.8%) major abnormalities were identified accurately by trainees.

## Diagnostic accuracy

The mean ± SD for diagnostic accuracy (maximum = 1) after history alone (*Figure 1*, $T_1/C_4$) was 0.26 ± 0.19; after history and physical examination (*Figure 1*, $T_2/C_4$) 0.34 ± 0.22; after history, physical examination, and ECG (*Figure 1*, $T_3/C_4$) 0.49 ± 0.22; after history, physical examination, ECG, and PHHE (*Figure 1*, $T_4/C_4$) 0.75 ± 0.28 (*Figure 5*). There was a statistically significant improvement of diagnostic accuracy when adding PHHE to the three other examination modalities (Wilcoxon singed-rank test, $Z = -7.761$, $P < 0.001$).

# Discussion

The present study is the first large prospective study involving medical students and junior doctors to show that PHHE is sufficiently intuitive and improves the final clinical diagnosis of patients with known or suspected heart disease over and above history taking, physical examination and ECG interpretation. We found a dramatic improvement in trainees' sensitivity, PPV and NPV in detecting or ruling out moderate-to-severe LV systolic dysfunction and valvular disease when using PHHE on the top of physical examination.

In the Duke LEAP,[7] 20 medical house officers without any previous experience in echocardiography participated in a standardized 3 h training programme. This large study (537 subjects) showed that despite the brief training, PHHE substantially improved the assessment of LV systolic function, MR, AS, and pericardial effusion over history and physical examination. Agreement between PHHE performed by trainees and standard echocardiography was 75% for moderate-to-severe LV systolic dysfunction, 79% for moderate-to-severe MR, 92% for aortic valve thickening or immobility, and 98% for moderate-to-large pericardial effusions, findings that closely resemble ours. In a study by Kobal *et al.*,[11] students after 18 h of training at PHHE correctly identified 75% (180 of 239) of the pathologies, whereas experienced cardiologists using their physical examination skills only detected 49% (116 of 239) ($P < 0.001$). In a study by Croft *et al.*,[8] 9 internal medicine residents underwent a week of training

(3 h/day for 5 days reviewing images and 1 h/day for 5 days performing supervised echocardiograms). Major findings (e.g. moderate-to-severe LV systolic function) were correctly identified in 92% of patients and minor findings (e.g. mild MR, mild LV systolic dysfunction) in 75%. Even though the sensitivity for LV systolic dysfunction in the study by Croft was higher than the one in the present study, the incremental difference from physical examination and history is practically the same, highlighting the additive effect of PHHE on clinical diagnosis. In another study of 50 patients with acute decompensated LV failure,[12] after minimal training (20 scans), internal medicine interns managed to detect with the use of PHHE, an EF $<40\%$ with excellent sensitivity (94%) and specificity (94%). A recent study[13] of 189 patients referred for initial cardiology outpatient consultations at two tertiary hospitals showed that the use of PHHE reduced the number of referrals for formal echocardiography (from 50.3 to 33.9%), increased the number of patients with a diagnosis at the end of the consultation (74.6% from 23.3%), and increased the number of discharges (54 from 17). In a study by Hellmann's group,[14] 10 non-cardiologists performed cardiac examinations on 354 general medical in-patients first by physical examination and then by PHHE (after minimal training—performed 5 supervised echocardiograms and underwent 6 h of echocardiogram interpretation training). With the use of PHHE, there was an improvement in assessing LV systolic function (from 46 to 59%, $P = 0.005$) but no improvement in diagnosing valvular lesions.

The American Society of Echocardiography[15] have recommended level II (a total of 150 personally performed examinations and 300 interpreted studies) training in order to independently perform and interpret PHHE. This was primarily based on the grounds that 'inadequate information and misinterpretation' can introduce pitfalls in the application of bedside PHHE. However, the potential decline in physical examination skills, misinterpretation of physical signs (as high as 20.3% of physical examinations performed by final-year medical students in the present study), and limitations of history taking can lead to diagnostic errors. Incorporating PHHE to clinical examination may act as a clinical 'gate-keeper' and leads to reducing errors and more accurate clinical diagnoses. Achieving level II or higher echocardiographic training is always desirable; however, it may be impractical considering the time expenditure required to be compliant, particularly for junior doctors. PHHE should not be considered as an echocardiographic examination as such but rather a clinical tool similar to the stethoscope or ECG. While basic training in ECG and echocardiography is mandatory in all junior doctors undergoing specialist training in cardiology, PHHE use extends its usefulness beyond cardiology in a way similar to the stethoscope and a brief bedside tutorial should normally suffice. It clearly enhances the diagnostic accuracy over history taking and physical examination alone and does not replace the standard echocardiography.

The reference standard for this study was the clinical diagnosis reached by the consultant cardiologist who was fully accredited in echocardiography. Comparison of PHHE with standard echocardiography would be beyond the scope of the current study as (i) previous studies have already validated the diagnostic accuracy of PHHE against standard echocardiography in the hands of experienced operators[3] and (ii) the main focus of the present study was the improvement of bedside clinical diagnosis with the use of PHHE after a brief tutorial.[3] Despite the fact that our patient cohort was unselected and consecutive, some pathology such as aortic dissection or acute myocardial infarction with potential complications were not tested so that the diagnostic accuracy of our findings in the acute setting may need to be evaluated in further studies. Nonetheless, this is the first large study to date testing the value of PHHE in the hands of medical students and junior doctors with no previous exposure to echocardiography, demonstrating that an intuitive approach to PHHE can improve the diagnostic accuracy over and above history taking and physical examination. This basic bedside echocardiographic examination (PHHE) can substantially improve the confidence of medical students in understanding various cardiac pathologies, which would otherwise be impossible with history and physical examination alone. Finally, correlating history and physical findings with a visual image of the heart enhances the learning experience and leads to the improvement of their examination skills.

PHHE represents a new, bedside imaging modality that could become a useful adjunct of the clinical examination and should not be viewed as a replacement or a shortcut to the standard echocardiogram. Even in the hands of medical students with only minimal training, PHHE improves diagnostic accuracy over and above history and physical examination. The portability of PHHE and their affordable cost by individuals will allow this new technology to become a valuable asset to medical education, particularly in the clinical curriculum.

# Supplementary data

Supplementary data are available at *European Heart Journal – Cardiovascular Imaging* online.

**Conflict of interest:** none declared.

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**IMAGE FOCUS**

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# Multimodality imaging of right ventricular perforation secondary to pacing lead migration

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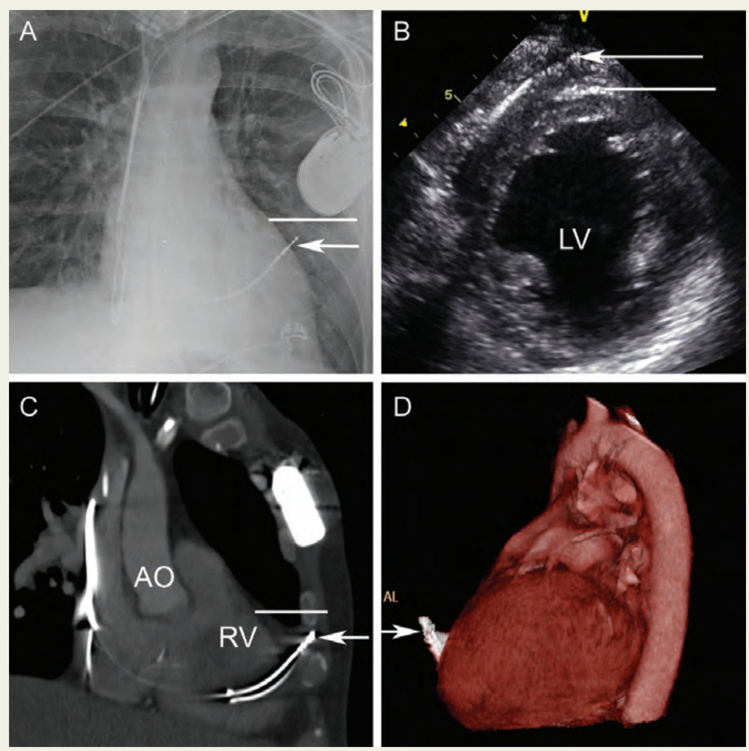
A 69-year-old male with an implantable cardiac defibrillator (ICD) *in situ* for ischaemic cardiomyopathy was transferred to our institute following a ventricular tachycardia storm and repeated shocks from his ICD. Shortly following his arrival, he developed acute pulmonary oedema and was transferred to our intensive care unit.

After stabilization, a chest X-ray was performed. This demonstrated cardiomegaly and protrusion of the right ventricular (RV) ICD lead tip beyond the boundary of the heart with appearances suggestive of perforation (*Panel A*). Although a transthoracic echocardiogram confirmed an extension of the pacing wire beyond the pericardium, the precise point of perforation could not be ascertained (*Panel B*). Accordingly, a chest computed tomography (CT) scan was performed, which confirmed RV perforation and also the anatomical point to be the free wall. After careful consideration, the lead was extracted without complication, using a hybrid laser lead extraction and the thoracotomy procedure under general anaesthesia.




Cardiac chamber perforation is a recognized a serious complication of ICD implantation (0.6–5.2%) and is associated with the use of steroids and anticoagulants, pacemaker lead design and placement, and also patient age, sex, and body habitus. The identification of lead perforation may be initially suggested by a chest X-ray, although additional information with chest CT is now emerging as a useful adjunctive tool by virtue of its three-dimensional isotropic imaging capabilities.

The current case firstly demonstrates the multimodality imaging findings of RV ICD lead perforation and secondly the clinical utility of chest CT to confirm not only the presence, but also the precise anatomical point of pacing lead perforation.

(*A*) Chest X-ray demonstrating protrusion of the ICD lead tip (closed arrow) extension beyond the pericardium (open arrow). (*B*) Transthoracic echocardiogram (parasternal short-axis view) showing the ICD lead tip extending anteriorly beyond the pericardium with the ICD lead tip (arrow) visualized anteriorly. (*C*) Curved multi-planar reformatted CT image demonstrating the extension of the pacing lead perforation beyond the pericardium and up to the anterior chest wall. (*D*) Volume rendered 3D chest CT image demonstrating the site and extent of the RV lead perforation. Ao, aorta; RV, right ventricle, and LV, left ventricle.