RESEARCH

A systematic review of pocket-sized imaging devices: small and mighty?

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Abstract

Introduction: Hand-held imaging devices are widely used in clinical practice and are a useful tool. There is no published review examining the diagnostic parameters achieved with these devices in clinical practice.
Methods: We searched three online medical literature databases (PubMed, EMBASE and MEDLINE) for all literature published up until January 2018. We selected studies that (1) were conducted in the adult population; (2) used a truly hand-held device; (3) featured sensitivities and/or specificities on the use of the hand-held scanner. We extracted and summarised the diagnostic metrics from the literature.
Results: Twenty-seven articles were excluded from the initial 56 relevant articles, as the device featured was not truly hand-held. Ultimately a total of 25 studies were analysed. Sixteen studies were carried out by experienced users, seven by users with little previous experience and two studies by nurses. High diagnostic parameters were achieved by all three groups when scanning cardiac pathology and intra-abdominal structures. Training of non-expert users varied, taking a mean of 21.6 h. These hand-held devices can change diagnoses at the bedside and be used as gate-keepers to formal echocardiography. Individual studies show them to be cost-effective.
Conclusion: Hand-held echocardiography is a useful tool in the hands of experts and novices alike. Studies conducted are highly heterogeneous making it difficult to pool data for the diagnostic metrics. Further studies with rigorous methodology are needed to evaluate the true diagnostic potential in the hands of non-experts and in the community as well as to validate training protocols.

Key Words

- pocket-size imaging devices
- hand-held ultrasound
- echocardiography
- sensitivity

Introduction

The introduction of echocardiography was transformative. By allowing direct visualisation and measurement, it improved the understanding, and simplified appreciation of cardiac structure and function in health and disease. It changed medical practice and continues to play a crucial role in patient care. The first machines were large and virtually immobile. In 1995, Sonosite began developing battery-powered devices culminating in the release of the Sonosite 180 (1), the first hand-carried device, weighing just under 3 kg. Other hand-carried devices have since been released (including the Sonosite Heart and MicroMaxx, and the Philips OptiGo). Further miniaturisation has resulted in devices designed to fit a physicians' pocket, such as the Acuson P10 (Siemens) and the Vscan (GE). This latter device weighs only 400 g and features colour flow mapping (CFM). Such devices have made

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hand-held echocardiography (HHE) accessible to clinicians and patients at the 'point of care'.

Miniaturisation comes at a cost. Small devices may be less robust, more easily misplaced and misappropriated than larger devices. More importantly, image quality and 'functionality' might be compromised as portability increases. Hand-held devices possess small screens and reduced computing power compared with standard echocardiography and all lack spectral Doppler capability. This restricts the users' ability comprehensively to assess pathology according to current guidelines, making the utility of HHE in everyday clinical practice uncertain.

Despite these limitations hand-held scanners provide the clinician with images of the patient's cardiac pathology rather than requiring them to use clinical signs as surrogate markers of disease. Physical examination skills have declined, especially among junior doctors (1, 2). This, coupled with the belief that basic scanning skills readily can be learned, has led some to describe HHE as the 'stethoscope of the future', augmenting the physical examination skills of both novice and expert (3, 4). Its relatively low cost makes it a useful tool in screening for rheumatic heart disease in developing countries (5). Medical students trained in echocardiography were superior to cardiologists restricted to physical examination with a stethoscope in correctly identifying the valvular pathology (6). Furthermore, medical residents more reliably can detect left ventricular systolic dysfunction (LV SD) and pericardial effusion using point of care echocardiography than through standard physical examination (7).

However, these and many other studies commonly included in contemporary reviews (8) utilised hand-carried, rather than the smaller hand-held, devices. We aimed to perform a systematic review of all the studies using truly hand-held devices and that reported aspects of diagnostic utility. The aim was to answer the following questions:

1. What are the diagnostic performances of experts and novices using HHE?
2. What training is needed for safe and proficient use of HHE?
3. What constitutes a comprehensive and clinically useful HHE exam?

Methods

We searched three online medical literature databases (PubMed, EMBASE and MEDLINE) for all literature published between January 1978 and January 2018 using the search strategy: ('Vscan' OR 'Point of Care Systems' OR 'portable' OR 'pocket' OR 'hand-held') AND ('cardiac ultrasound' or 'echocardiography'). The search was limited to 'human studies' and those available in English.

Data collection

We read the titles and abstracts of the resultant 3045 articles and selected for further study those that fulfilled our selection criteria of: (1) using a truly hand-held device; (2) featuring sensitivities and/or specificities of HHE with respect to specific conditions. We excluded studies reported only as conference abstracts, studies with medical student operators and studies conducted in a paediatric population. A flow diagram for the search and selection process can be found in Fig. 1. References of selected papers were manually searched to identify additional studies of interest.

We extracted the following information from the papers for analysis: type of hand-held ultrasound (HHU) device used, who used it, clinical setting, any training (prior to, or for the purposes of, the study), particular structures scanned, image quality (feasibility) and diagnostic metrics for the detection of LV SD, valvular disease, pericardial effusion, aortic and inferior vena caval (IVC) characteristics.

Not all articles clearly described the prior scanning experience of the HHE operators. Unless the authors stated that the clinicians were experienced, we categorised them as inexperienced.

As studies used differing scanning protocols, we divided studies into those incorporating a single assessment (e.g. LV SD) and those including more extensive echocardiographic assessment.

Results

The initial search yielded 3045 publications of which 2989 were excluded after reading the abstracts, leaving 56 potentially relevant studies. Following analysis of the full texts, we excluded 27 studies based on the type of HHE device used. Of these excluded studies 17 used the hand-carried type of OptiGo (Philips) device rather than the hand-held version (or the hand-held nature of the device could not be verified); four studies used SonoHeart (Sonosite), one used Sonosite 180 (Sonosite) and four used MicroMaxx (Sonosite); these hand-carried devices had been referred to as 'hand-held' within the abstract

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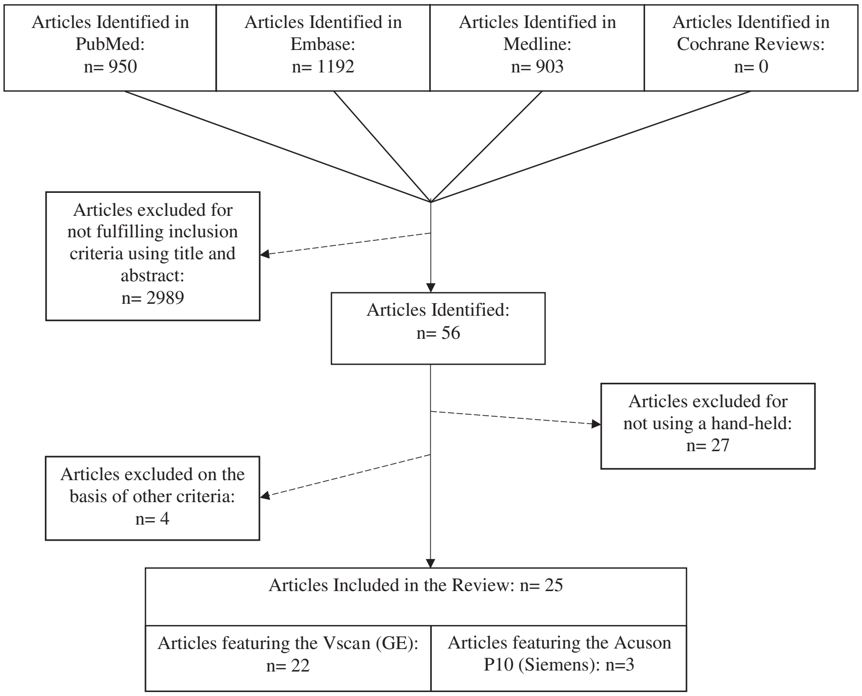

Figure 1
Flow chart of the study selection process.

and/or title. The authors of one study failed to state exactly which HHE was used. A further four studies were excluded because they lacked a valid 'gold standard' against which to compare the diagnostic accuracy of HHE. We therefore analysed 25 studies in our review, 3 featuring the Acuson P10 (Siemens) and 22 the Vscan (GE).

The 25 selected studies were published between 2009 and 2017. Fourteen studies were European (9, 10, 11, 12, 13, 14, 15) (seven from Norway (16, 17, 18, 19, 20, 21, 22)), five from Japan (23, 24, 25, 26, 27), five from USA (28, 29, 30, 31, 32) and one from India (33). We considered the findings in three groups: (1) scans performed by experienced users (n=16); (2) scans performed by non-expert physicians, with little or no prior experience (n=7); (3) scans performed by nurses with variable experience (n=2).

HHE scans by all users

Details of all studies, their protocols and main findings are shown in Table 1. Population characteristics, numbers of patients scanned and duration of HHE examinations are shown in Table 2.

Most studies were of HHE in the assessment of LV size and function, detection of regional wall motion abnormalities (RWMA) and valvular assessment (including CFM). Ten studies we felt provided a 'comprehensive' cardiac assessment. Their protocols for scanning included the obtaining of images from at least the parasternal long-axis (PLAX), parasternal short-axis (PSAX) and three apical views (10, 11, 14, 16, 17, 18, 23, 25, 27, 28). Only three studies featured fewer views (excluding the eight studies featuring focused assessments). Although a further three studies stated they used standard cardiac protocols, their details could not be confirmed (9, 12, 24). The focused studies included determining LV function (20, 30, 29), detection of pleural or pericardial effusions (21, 22, 32) or pre-defined lung-cardiac-IVC protocols for the investigation of dyspnoea (15, 24). Subcostal views were included in 30% of the comprehensive studies and 27% of all protocols. Studies following a comprehensive protocol took a mean of 4.4 min, and 4.8 min for studies also featuring pericardial and RV assessments.

What can we see from a meta-analysis of the HHE data?

We applied meta-regression techniques to the performance parameters for the detection of global LV SD and found that experienced users performed better than non-experts (P=0.0295), even if the outlying studies (19, 20) were removed from the analysis. For AS, AR and MR there were no significant differences between experts and non-experts; however, the heterogeneity was high and the number of studies was considerably smaller (Supplementary Table 1, see section on supplementary data given at the end of this article). These findings need to be treated with caution, as there is high level of inconsistency (I^2 values of >80%) in performance across the studies (Supplementary Table 1).

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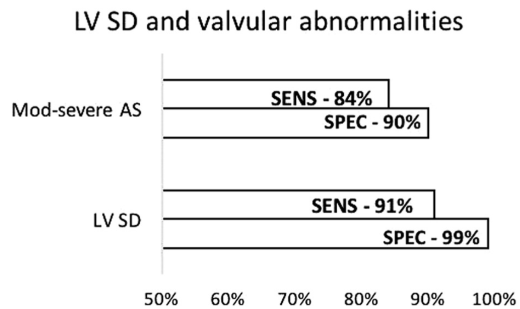
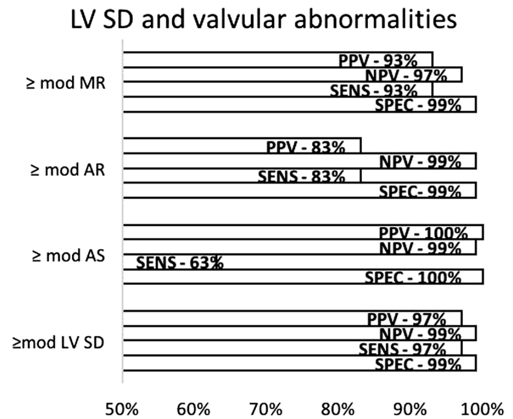
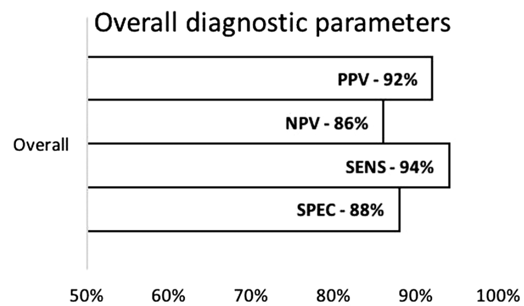
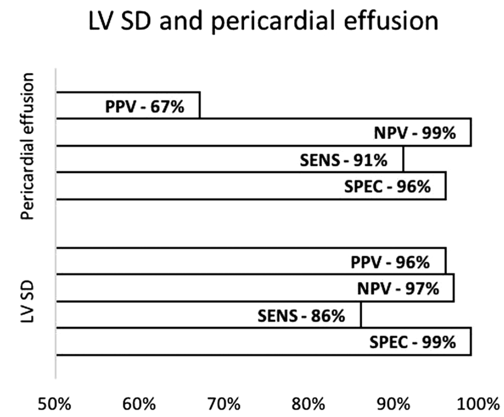
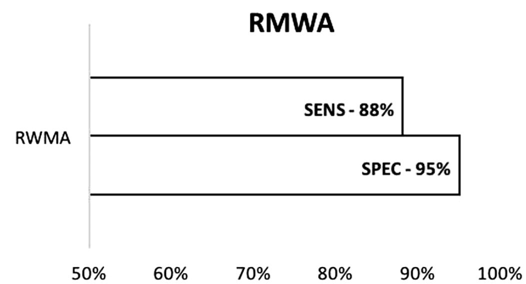
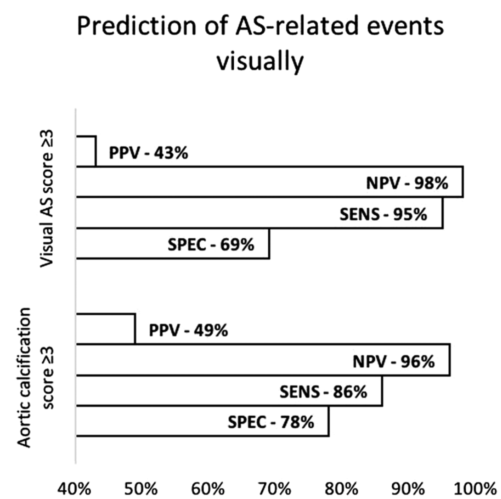
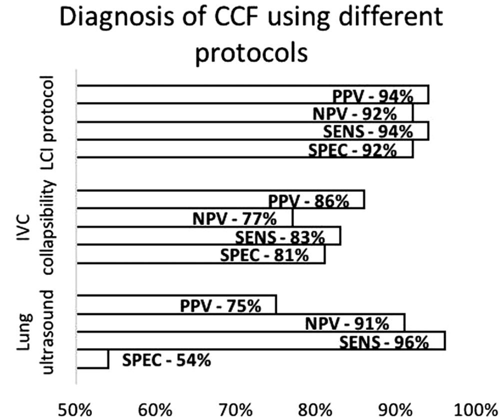
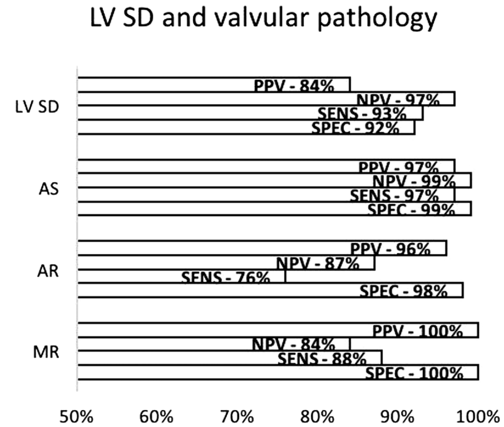
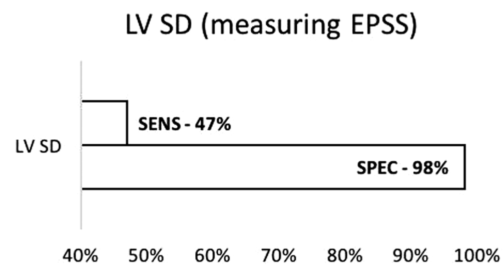
Table 1 Summary of studies conducted using pocket-sized imaging devices.

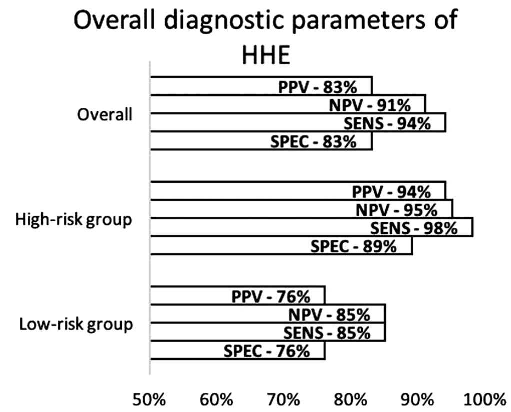
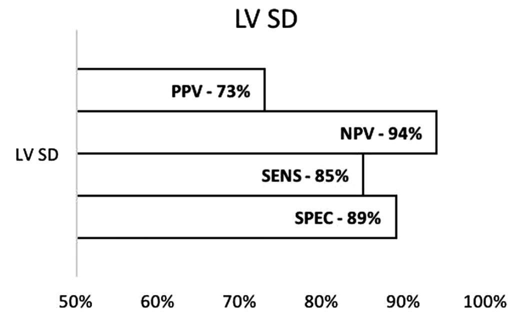
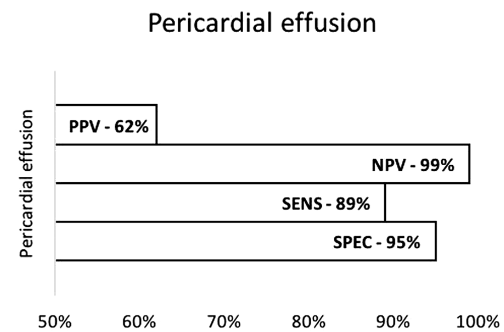
Authors	Aims	Study design	Who scanned	Patients (*n*)	Diagnostic parameters	Main results
Expert users						
Abe *et al.* (23)	To assess the feasibility of screening for AS using HHE	Patients referred for assessment for a systolic murmur had a physical exam by a cardiologist and HHE exam by expert sonographer. Both diagnostic values were compared separately to the findings of sTTE	Expert sonographer (ASE level III)	147		• Strong correlation between visual AS score obtained using HHE and AVAI by sTTE • Aortic calcification score ≥3 was optimal for detecting severe AS • If only pts with aortic calcification score ≥3 were referred for sTTE, unnecessary sTTE could have been avoided in 75 pts (58%)
Andersen *et al.* (16)	To evaluate the use of HHE as an adjunct to physical examination on ward rounds	Patients admitted while one of the participating cardiologists was on-call for general medicine. Patients had a physical exam by cardiologist and HHE exam by expert sonographer. Both diagnostic values were compared separately to the findings of sTTE	Cardiologists (level of experience not specified)	119		• Good agreement between sTTE and HHE for: ○ Global and regional LV function (r=0.92, r=0.95 respectively) ○ Valvular function (AR, MR, TR) (r=≥0.81) ○ Pleural effusions (r=0.82) • One significant pericardial effusion was missed by HHE
Di Bello *et al.* (10)	To evaluate the incremental value of HHE in addition to hx, physical examination and ECG +/– CXR	Patients referred for inpatient cardiology consultation (indications: MI, SOB, arrhythmias or pre-surgery) underwent the standard clinical examination, ECG +/– CXR and HHE. The findings were recorded and discussed at a meeting between three clinical cardiologists, who made the call of whether HHE influenced the patient care	Cardiologists (ASE level III)	443		• Good agreement between HHE and sTTE (k=0.82) • In addition to the hx, standard physical examination, ECG +/– CXR, HHE had a positive impact in 73% of cases: ○ Changing the initial diagnosis in 26.2% of pts ○ Adding significant clinical information in 21.9% of pts ○ Verifying the diagnosis in 25.3% of cases

Biais *et al.* (11)	To evaluate the diagnostic utility of HHE in emergency department	Patients admitted to the emergency department were scanned with HHE by one of two intensivists, after a medical history and examination were obtained. The findings were compared to sTTE performed by another intensivist. Both intensivists had the same clinical information available to them	Intensivists (EAE level II)	151		• No statistical difference for measurement of LV EF by HHE vs sTTE, and were well correlated ($r = 0.79$) • HHE adequately: ○ Graded LV SD ($k = 0.87$) ○ Identified presence of LVD and LVH ($k > 0.60$) ○ Assessed RVD and RV SD, identified pericardial effusion and tamponade ($k = 0.63–1.00$) • Image quality was sufficient to address all clinical questions
Fukuda *et al.* (26) Acuson P10	To investigate the feasibility and accuracy of HHE	Patients referred for LV function assessment by sTTE were scanned using HHE and sTTE	Expert sonographer and experienced physician (level of experience not specified)	125		• There was good agreement of HHE with sTTE for: ○ LV systolic and diastolic dimensions ($r = 0.91$ and 0.95 respectively) ○ LA dimensions ($r = 0.93$) ○ Aortic diameter ($r = 0.87$)
Furukawa *et al.* (27)	To assess the utility of a AS calcification score obtained using HHE for predicting AS-related events	Patients referred with SEM, or were known AS, were scanned using HHE and sTTE. A visual AS and calcification scores were calculated. Patients were followed up for 18 months looking at AS-related events (cardiac death and valve replacement)	Cardiac sonographer (ASE Level III)	130		• Patients with visual AS and calcification scores <3 had a 98% event-free survival • While patient group with visual AS score ≥3 and calcification score ≥3 had a 62% event-free survival • In multivariate analyses a visual AS score >3 was an independent determinant of AS-related events

(Continued)

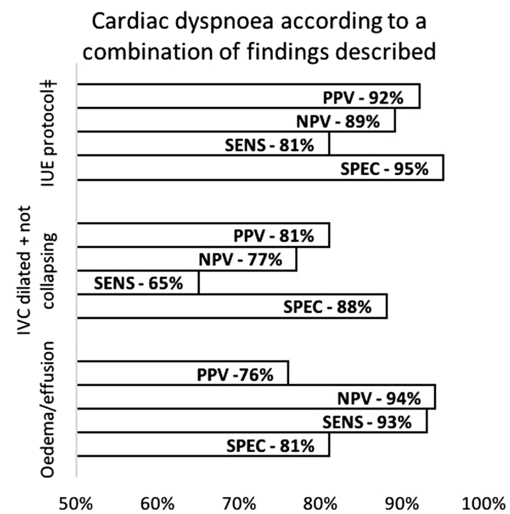
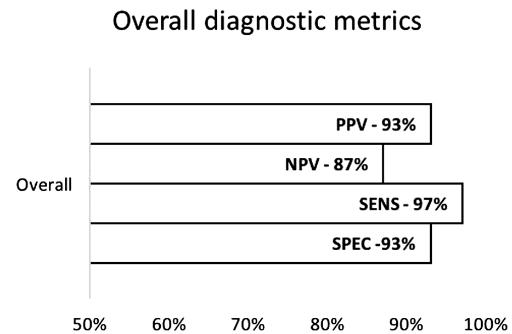
Table 1 Continued.

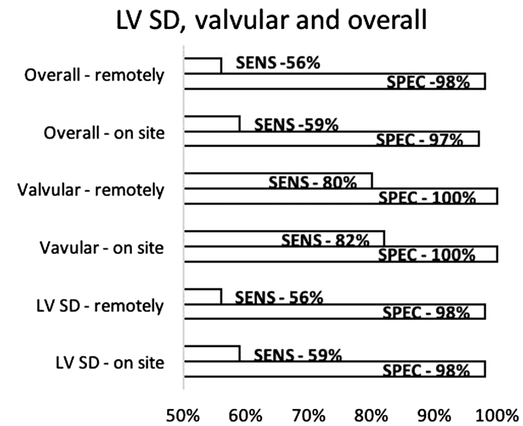
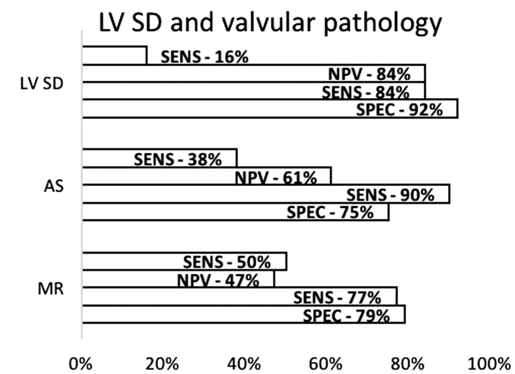
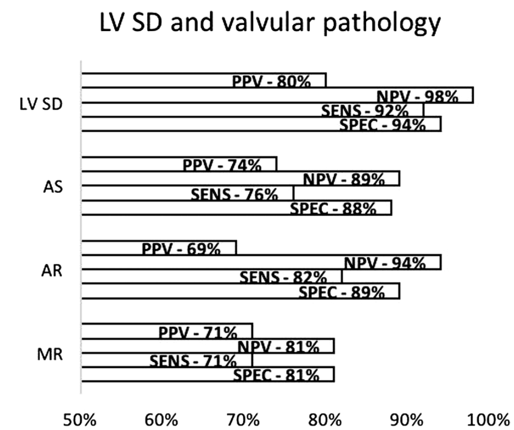
Authors	Aims	Study design	Who scanned	Patients (*n*)	Diagnostic parameters	Main results
Kajimoto *et al.* (24)	To determine the diagnostic value of HHE to differentiate between the lung and cardiac causes of SOB using the LCI examination	Pts admitted with SOB had hx taken, physical exam, bloods (inc. BNP), ECG and CXR performed before a HHE LCI exam took place. A final diagnosis was made by cardiologist, which was compared to a consensus diagnosis decided by two cardiologists and one pneumologist	Cardiologists (level of experience not specified)	90		• LCI protocol allows rapid and extremely accurate assessment of dyspnoea (cardiac vs pulmonary) • LCI exam had higher diagnostic accuracy for differentiating between cardiac/pulmonary SOB compared to lung ultrasound alone or in combination with BNP assay • Lack of radiological evidence of HF on CXR does not exclude CCF
Khan *et al.* (28)	Investigate the accuracy of HHE compared to sTTE	In-pts referred for sTTE (excluding patients on CPAP and ICU) were scanned. The cardiology registrar scanning had only the indication for scan available to them. The findings from sTTE and HHE were compared	Senior cardiology registrars (ASE Level II)	240		• Overall HHE vs sTTE agreement was high (85%) • RWMA could not be assessed due to suboptimal visualisation of endocardial borders in eight of HHE and 6 of sTTE cases • Majority of false-negative results on HHE were clinically insignificant ○ 5 cases of LV EF read as normal but confirmed at moderately reduced on sTTE ○ 2 cases moderate AS ○ 13 cases of RWMA
Kimura *et al.* (29) Acuson P10	To investigate the quality and accuracy of HHE in assessing LV SD (using EPSS) and LA enlargement	A sonographer obtained a PLAX loop on in-patients referred for sTTE. Technically difficult studies were excluded from analysis. Measurements were compared to the ones obtained using sTTE	Experienced sonographer (level of experience not specified)	61		• HHE provided adequate assessment of LV SD and LA enlargement • Image quality was lower in HHE studies compared to sTTE (especially in ICU) • Reduced accuracy is likely partly due to limitations of HHE, and partly due to the difference between qualitative and quantitative criteria for assessment

Kitada *et al.* (25)	To test the feasibility and diagnostic accuracy of HHE and explore the cost-effectiveness of HHE as an initial screening tool	Patients referred for sTTE were examined using HHE by an expert physician and sTTE straight after. Results from HHE were compared to sTTE and ECG findings. The investigators compared the cost impact of implementing different combinations of screening methods	Expert physician (level of experience not specified)	200		• There was good agreement between sTTE and HHE (90%) • Higher diagnostic metrics were obtained when only high-risk pts were included • HHE improved workflow reducing waiting for sTTE • Screening using HHE before sTTE results in cost reduction of 35% and high diagnostic metrics
Olesen *et al.* (9)	To assess the utility of HHE in screening for LV SD in an elderly population	Pts (≥75 year) with and without CVD recruited from geriatric OPD and background population were recruited. Expert echocardiographers scanned the pts using HHE and sTTE. Scans were stored on the system, assessed and compared	Expert echocardiographers (Level III)	260		• HHE is a useful tool to screen for LV SD in the elderly • HHE has a high NPV for LV SD (0.95) • HHE concluded no LV SD in ten cases where sTTE confirmed mild-moderate LV SD • Poor image quality made 14 scans uninterpretable
Philips *et al.* (32)	To evaluate the utility of HHE for detection of pericardial effusions, pleural effusions, interstitial oedema, pneumonia and central line placement in CCU	Pts admitted to CCU over 9 months to a tertiary centre, and for whom a CXR was being requested were included. HHE findings were interpreted at bedside, while CXR was reported by an experienced radiologist and findings were compared. All pts also had sTTE and some underwent CT scanning (n=38)	Physician (4 years of HHE experience)	64		• High sensitivities and NPV for pericardial effusion and LA enlargement (HHE vs sTTE) • Good concordance values for (HHE vs CXR) ○ Pneumonia (92%) ○ Central line (81%) ○ Interstitial oedema (80%) ○ Pleural effusion (77%) • In 12 discordant examinations for interstitial oedema where CXR was positive and HHE was negative, 67% resolved on follow-up within 24 h

(Continued)

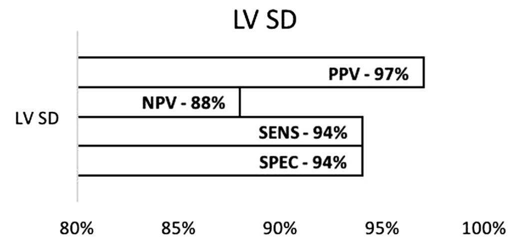
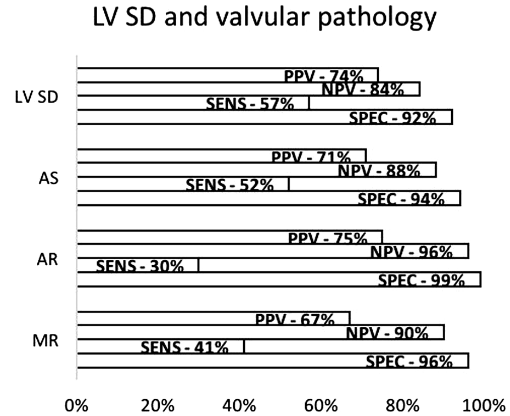
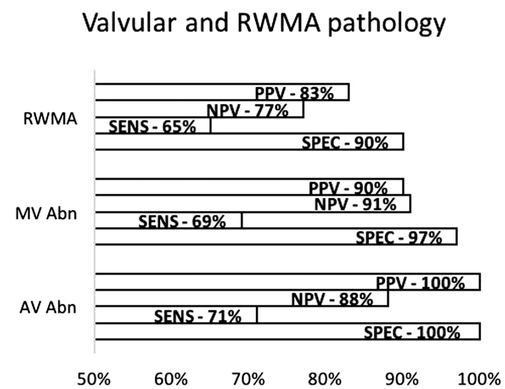
Table 1 Continued.

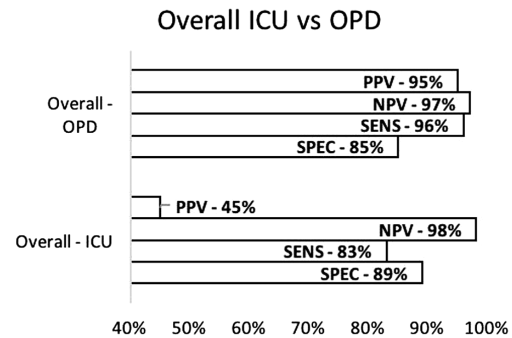
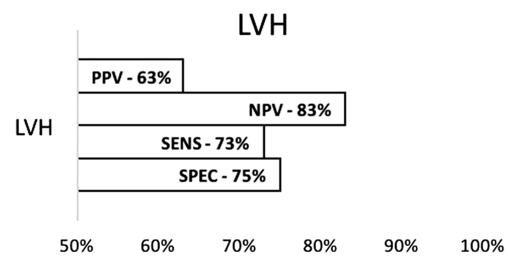
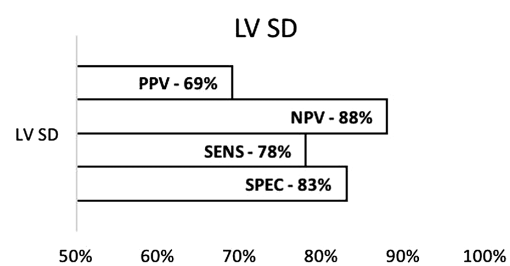
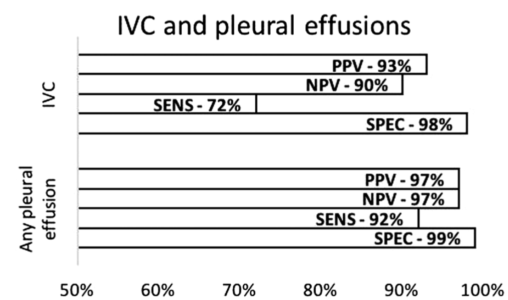
Authors	Aims	Study design	Who scanned	Patients (*n*)	Diagnostic parameters	Main results
Sforza *et al.* (15)	To assess the utility of HHE in discerning between cardiac and non-cardiac dyspnoea in patients admitted to ED	Patients admitted to ED had standard investigations (examination, CXR, bloods). These patients were later scanned using HHE by an ED physician. A second ED physician determined the diagnosis taking into account all clinical findings and response to therapy (blind to HEE findings). A third ED physician interpreted all the HHE images (blind to final diagnosis)	ED physician (ASE Level III)	68		• HHE is a useful extension of the clinical examination and was quick to perform • Highest diagnostic parameters, accuracy (90%) and AUC (0.894) for the detection of cardiac dyspnoea were achieved for a combination of: (‡ interstitial oedema OR pleural effusion) AND (LV EF <40% OR dilated IVC)
Skjetne *et al.* (17)	Diagnostic value of HHE at the bedside in the cardiac unit	Pts admitted to the cardiology unit were examined and a primary diagnosis was established by a junior and senior doctor from hx, clinical exam, lab tests and initial imaging. HHE was then performed by one of the cardiologists. Two internal and one external cardiologist examined the case, and based on the EAE guidelines, judged how much impact HHE had in that particular case	Cardiologist (level of experience not specified)	119		• HHE examination achieved: ○ A change in primary diagnosis in 16% pts ○ Verification of primary diagnosis in 29% pts ○ Additional diagnosis made in 10% pts ○ No diagnostic usefulness in 45% pts • Mean time to perform the examination was 4.4 min

Non-experts scanning						
Bansal *et al.* (33)	1. Test feasibility of web-based training module (live transmission of images to off-site trainer + guidance) 2. To compare the web-based resource to traditional onsite training	Patients undergoing cataract surgery were screened for cardiovascular disease using HHE. Physicians were trained either with onsite training or remotely (1 h lecture followed by hands-on training). Expert analysis of images served as the reference examination for the diagnostic metrics, sTTE was only performed if major abnormalities were found with the Vscan	Physicians ($n = 17$)	968		• There was no significant differences in accuracy of findings reported by onsite vs remotely trained physicians • Onsite trained physicians obtained better quality of images than remotely trained physicians • 14.2% of pts in the study who were considered to have no CVD were indeed found to have significant cardiac pathology on echo • 88.9% of scans had excellent, good or fair image quality • Severity of lesions was underestimated by one grade in 11.2% of cases and overestimated in 2%
Gulič *et al.* (13)	To investigate the feasibility and accuracy of using HHE as a screening tool for AS in the hands of non-cardiologists	Pts referred for assessment of new murmur were scanned. Scans performed by trainees and analysed by them, and a cardiologist separately	Physician and two emergency physicians • Specifically trained	200		• Useful screening tool even in the hands of non-cardiologists as reflected by high sensitivity and specificity • No significant difference between HHE and sTTE for detection of severe pathology • The difference between the prevalence of >mild AS and MR detected by cardiologist vs non-cardiologist was not statistically significant
Mjøstad *et al.* (18)	Use of HHE in the hands of medical residents with limited experience	A resident would take a history, examine the patients admitted to the hospital and perform supplemental tests before using HHU to help make the diagnosis. Findings were compared to sTTE	Medical resident ($n = 6$) • Specifically trained	199		• Use of HHE allowed identification of important and relevant cardiovascular pathology • Strong correlation between HHE findings and sTTE (esp. for LV SD, pleural and pericardial effusion ($r \geq 0.83$)) • There was some under and overestimation of ventricular dysfunction and valvular pathology

(Continued)

Table 1 Continued.

Authors	Aims	Study design	Who scanned	Patients (*n*)	Diagnostic parameters	Main results
Razi *et al.* (30)	Test the ability of internal medicine residents to detect LV SD in patients presenting with CCF	Pts were scanned by one of the medical residents blinded to hx, physical exam and all other clinical findings	Medical residents (*n*=3) • Specifically trained	50		• LV SD identified with superior accuracy compared to clinical examination, blood tests and ECG findings (on average 22 h prior to sTTE results were available) • Ability to detect LV SD was best in LV EF<30% and >50% (sensitivities 100%)
Ruddox *et al.* (19)	To evaluate the accuracy of HHE in the hands of internal medicine residents on-call	A focused cardiac assessment was performed on the patients seen while on-call (if there was an indication to do so)	Medical residents (*n*=26) • Specifically trained	303		• HHU examination allows ruling out significant disease as was reflected in its high specificity and NPV values • No exam exclusion due to poor image quality • Only 2/3rd of residents used the skills more than monthly, indicating that the skill was underused
Giusca *et al.* (14) Acuson P10	To investigate the feasibility of HHE in the hands of cardiology trainees with limited echocardiography experience to acquire and interpret images	Patients admitted to the cardiology ward in a tertiary cardiac centre were scanned by a cardiology trainee using HHE and with sTTE (within 24 h)	Six cardiology trainees (basic level of EAE training)	56		• Agreement between HHE and sTTE varied: ○ AV abnormalities (*k*=0.76) ○ MV abnormalities (*k*=0.72) ○ WMA (*k*=0.56) • High false-negative value detecting WMA using HHE • HHE missed one pericardial effusion out of a total of two detected by sTTE (extent of pericardial effusions not stated)

Michalski *et al.* (12)*	To explore the feasibility and accuracy of HHE in the hands of physicians with different levels of experience	Patients admitted to ICU for ACS/HF and OPD pts referred for sTTE after a similar admission were enrolled. Mechanically ventilated pts were excluded. sTTE was completed within 24 h of HHE exam	Cardiologist and cardiology resident • Specifically trained	220 pts (ICU *n* = 110, OPD *n* = 110)		• Diagnostic accuracy of HHE is moderate to very good in the hands of a resident and good to excellent in the hands of an experienced cardiologist • Cardiologist completed the HHE examinations quicker than the resident • Correlation between HHE exams and sTTE was excellent for all parameters measured
GPs						
Bornemann *et al.* (31)	To evaluate whether GPs, after minimal training, can use HHE to calculate LVMI and detect LVH	GPs scanned patients referred for sTTE in a cardiology clinic and on the wards. HHE were compared to sTTE performed within 14 days. Images were verified by a cardiologist	One GP and three GP residents • Specifically trained	101		• Feasible for GPs to detect LVH using HHE, but diagnostic parameters relatively low • LVMI and septal wall thickness measurements were not significantly different between HHE and sTTE • LVEDD and posterior wall thickness measurements were found to be significantly different between HHE and sTTE – possibly as the GPs found these more challenging
Mjølstad *et al.* (20)	To evaluate whether GPs can assess for LV SD (by measuring sMAE) in patients at risk/developing/established CCF	GPs scanned patients in primary care setting, sMAE was measured afterwards, and images were reviewed by an independent cardiologist. Same patient was scanned by a laptop-based sTTE	Seven GPs across three practices	92		• HHE in the hands of GPs offered the same accuracy for LV SD as the laptop-based scanner in the hands of the cardiologist • <5 min was added to consultations • After the video loops were reviewed by a cardiologist PPV and specificity increased
Nurses						
Dalen *et al.* (21)	To evaluate the accuracy of HHE to assess pleural effusions and the IVC by nurses in an outpatient HF clinic	Nurse took a hx, examined the patient and performed tests (BP, ECG, BNP) before performing HHE in OPD. The exam (consisting of IVC size and examining pleural cavities) was compared to sTTE by cardiologist	Two specialised CCF nurses • Previous experience with sTTE • Specifically trained	62		• HHE vs sTTE agreement was high for detection of pleural effusions (0.96), end-expiratory IVC size (0.89), end-inspiratory IVC size (0.79) • Nurses' findings were comparable to sTTE carried out by a cardiologist

(Continued)

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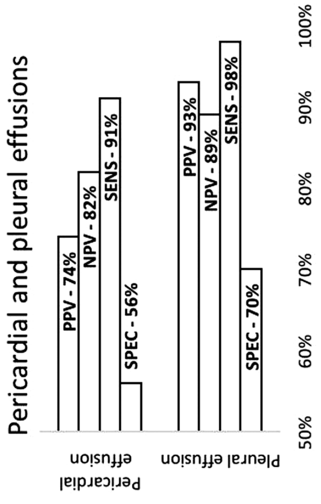
Table 1 Continued.

Authors	Aims	Study design	Who scanned	Patients (*n*)	Diagnostic parameters	Main results
Graven *et al.* (22)	To assess accuracy of HHE in the hands of nurses at detecting pleural and pericardial effusions in patients undergoing surgery	Pts were examined by one of the nurses using HHE. Findings were compared to sTTE examination (by an experienced cardiologist) and CXR findings interpreted by an experienced radiologist	Two nurses • No previous experience • Specifically trained	59		• High agreement for HHE vs sTTE for: pericardial effusion was high (r = 0.76) and pleural effusion (r = 0.81) • This is despite the image quality after cardiac surgery was suboptimal • Agreement for CXR vs sTTE for pleural effusions was low (r = 0.21 (P = 0.03))

A4C, apical 4-chamber; AA, abdominal aorta; AAA, abdominal aortic aneurysm; ACS, acute coronary syndrome; AHFS, acute heart failure syndrome; AR, aortic regurgitation; AS, aortic stenosis; ASE, American Society of Echocardiography; AV, aortic valve; AVA, aortic valve area; BP, blood pressure; CHD, coronary heart disease; CVD, cardiovascular disease; EAE, European Association of Echocardiography; ED, emergency department; EPSS, e-point septal separation; HF, heart failure; HHE, hand-held echo; Hx, history; ICU, intensive care unit; IVC, inferior vena cava; IVSd, interventricular septal end diastole; LA, left atrium; LCI, lung-cardiac-inferior vena cava; LV, left ventricle; LV EF, left ventricular ejection fraction; LV SD, left ventricular systolic dysfunction; LVD, left ventricular dilatation; LVEDD, left ventricular end-diastolic dimension; LVH, left ventricular hypertrophy; LVMI, left ventricular mass index; LV SD, left ventricular septum in diastole; MI, myocardial infarction; MR, mitral regurgitation; MS, mitral stenosis; MV, mitral valve; NPV, negative predictive value; OPD, outpatient department; PPV, positive predictive valve; Pt, patient; PWd, posterior wall in diastole; RV, right ventricle; RV SD, right ventricular systolic dysfunction; RVD, right ventricular dilatation; SDL, self-directed learning; SEM, systolic ejection murmur; sMAE, systolic mitral annual excursion; SOB, shortness of breath; sTTE, standard transthoracic echocardiography; TR, tricuspid regurgitation; TV, tricuspid valve; WMA, wall motion abnormalities.

Funnel plots for LV SD can be found in Supplementary Fig. 1. The smaller studies demonstrate greater diagnostic values for LV SD as compared to the larger studies, and therefore present their findings more enthusiastically, suggesting an element of publication bias.

HHE in the hands of experienced users

The various clinicians, cardiologists, echocardiographers, cardiology trainees and intensivists, performed scans in a variety of settings including on the ward by the bedside, outpatient department and emergency department. Fifty percent of studies with experienced clinicians used comprehensive protocols for scanning, and occasionally examined the IVC (n = 5) and abdominal aorta (AA) (n = 2). Feasibility of adequate image acquisition was high for comprehensive examinations, ranging from 94 to 100%, but was lower for examinations featuring abdominal structures (AA, IVC) ranging from 71 to 78% (16).

Four studies concentrated on assessing for specific pathology: (1) identifying cardiac causes of dyspnoea using the lung-cardiac-IVC (LCI) protocol (15, 24); (2) left ventricular systolic dysfunction (LV SD) (using EPSS as the measure) (29); (3) identifying pulmonary changes, pleural and pericardial effusions on CCU rounds (32).

The latter study (32), comparing HHE with sTTE and chest radiography, suggested that HHE might detect resolving pneumonia before radiography. Two studies opportunistically made use of other diagnostic modalities (such as CT and MRI) as comparators to HHE (16, 17) (if the patients had undergone such investigations as part of their standard care). Nevertheless, most studies (n = 12/14) compared HHE findings to sTTE (24) even if only a quarter of patients had sTTE (10). The two remaining studies used a clinical diagnosis as the 'gold standard' (15, 24).

The sensitivities, specificities, positive predictive values (PPV) and negative predictive values (NPV) reported for: (1) LV SD and valvular pathology can be found in Table 3; (2) RWMA and pericardial effusion in Table 4; (3) AA and IVC in Table 5; (4) all other diagnostic parameters featured are in Table 6.

HHE in the hands of inexperienced users

Less experienced participants (see Table 2) were required to perform comprehensive scans in only two studies – the remainder performing more focused assessments. The mean (s.d.) scan time for comprehensive and scans visualising the heart from at least the parasternal and apical positions (n = 5) was 5.7 min and 8.1 min (2.35)

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Table 2 The participants, and the patient population scanned by the expert, non-expert users and nurses.

	Experienced users	Non-experts	Nurses
Studies (*n*)	14	9	2
Patients (*n*)	2185	2189	121
Mean patients (s.d.)	156 (102)	243 (285)[a]	60 (2)
Who scanned?	Cardiologists, echocardiographers, cardiology trainees and intensivists	Medical residents, physicians, GPs	Nurses
Studies featuring comprehensive scans (*n*)	7/14	2/9	0/2
Length of comprehensive scan (min (s.d.))	4.4 (2.6)	5.7	n/a
Interpretation on the device (*n*)	12/14	7/9	2/2

[a]The overall mean (s.d.) was 243 (285), however, one study scanned patients undergoing cataract surgery in a surgical camp (35) screening 968 patients and skewing the mean. If this study was excluded from the calculation, mean (s.d.) would be 153 (91) patients.

respectively. In three studies scans were performed from a single viewing point. These focused on LV SD (20, 30) or left ventricular hypertrophy (LVH) (31). Images of sufficient quality as to allow assessment were obtained in 87 to 100% cases, but scanning lower abdominal structures was more difficult (AA: 50%, IVC: 77%) (18). Most measurements ($n=7/9$) were performed directly on the device rather than on computer software.

Two studies involved general practitioners (GPs), though only one was conducted in the primary care setting. The users measured septal mitral annular excursion (sMAE) (20), from apical 4-chamber (A4C) views, to diagnose LV SD achieving a NPV value of 88%, with a sensitivity of 78% (compared to sTTE). The second study was in a hospital setting where the GPs used HHE to detect and assess LVH in PLAX (31); the NPV of a normal HHE was 83% while sensitivity and PPV were 73 and 63% respectively.

HHE findings were compared to sTTE in all cases apart from one study where expert image re-analysis served as a benchmark, with sTTE being conducted if only major pathology was identified (33). Diagnostic utility for LV SD and valvular pathology are displayed in Table 3, while that for all other pathologies can be found in Table 6.

Nurses

Only two studies were conducted by nurses in the hospital setting (21, 22), scanning a total of 121 patients. Experienced nurses were able to detect pleural effusions and assess IVC size in a heart failure outpatient clinic with the same proficiency as a cardiologist who used sTTE (21). The investigators speculate that the nurses' ability to judge fluid status can improve heart failure management in this setting. In the second study, the nurses, who were unfamiliar with echocardiography, were trained to detect pleural and pericardial effusions (22). They achieved sufficient image quality in all cases and high agreement with sTTE, despite patients being scanned after cardiac surgery when image quality would be suboptimal. The agreement, sensitivity, PPV and NPV for pleural effusions were all superior for HHE as compared to chest radiography. For full study protocols and results refer to Tables 1, 4, 5 and 6.

Training of users to be able to use HHE

The way the extent of training was reported varied highly. Some studies reported the number of hours of training that the participants underwent, whereas others expressed this in days and months (18), the number of scans performed during training (30) or even level of training according to European Association of Echocardiography (EAE) (14). Overall (12, 18, 19, 20, 22, 31, 33), the number of hours in training (mean (s.d.)) was 21.6 (37) hours (ranging from 2 to 105 h). More limited single view scans required GPs to undergo a mean of 6 h of training. The mean number of scans performed by the physicians during the period of training was 94. These latter users were trained over months (18, 22) with some even completing 150 examinations (12).

Discussion

HHE is a promising tool with the potential to augment diagnosis at the bedside in the hands of novices and experts alike. Single studies show that it can be used as a triage tool prior to sTTE (25, 28), leading to cost-savings and shorter hospital stay (34). It has the potential to be used in screening and surveillance of AS given its high NPV for AS-related events (13, 27). Furthermore, the LCI

Table 3 Sensitivities and specificities for LV SD and valvular pathology.

Who scanned?	Author	LV SD Sensitivity (95% CI)	LV SD Specificity (95% CI)	LV SD PPV (95% CI)	LV SD NPV (95% CI)	Valvular pathology Sensitivity (95% CI)	Valvular pathology Specificity (95% CI)	Valvular pathology PPV (95% CI)	Valvular pathology NPV (95% CI)	Comparator	Definition
Experienced users	Abe *et al.* (23)	91%	99%			Mod-Severe AS – 84%	Mod-Severe AS – 90%			sTTE	LV SD = LV EF <50% visually for HHE AS detected based on either a) visual score criteria (aortic cusp's opening in PSAX) for each cusp: 0 = not restricted, 1 = restricted, or 2 = severely restricted; b) calcification score (degree of calcification): 1 = no calcification, 2 = mildly calcified (small isolated spots), 3 = moderately calcified (multiple larger spots), or 4 = heavily calcified. Table 1 for optimal cut-off values
	Andersen *et al.* (16)	97%	99%	97%	99%	AS-63% AR-83% MR-93%	AS-100% AR-99% MR-99%	AS-100% AR-83% MR-93%	MR-99% AR-99% AS-97%	sTTE	At least moderate LV SD; at least moderate AS/AR/MR. All pathology graded based on European Association of Echocardiography guidelines
	Biais *et al.* (11)	86% (69–94)	99% (96–100)	96% (80–99)	97% (93–99)					sTTE	LV SD = LV EF <50%
	Giusca *et al.* (14) Acuson P10					AV: 70.6% MV: 69.2%	AV: 100% MV: 97.4%	AV: 100% MV: 90%	AV: 87.5% MV: 90.5%	sTTE	Mitral valve (MV) abnormalities (e.g. thickened valves, ruptured chordae, coaptation defect, reduced opening), morphological abnormalities) and aortic valve abnormalities (e.g. thickened valves, coaptation defects, and reduced opening). Each abnormality was assessed individually and the result was presented in a binary way: present or absent
	Khan *et al.* (28)	93%	92%	84%	97%	AS: 97% AR: 76% MR: 88%	AS: 99% AR: 98% MR: 100%	AS: 97% AR: 96% MR: 100%	AS: 99% AR: 87% MR: 84%	sTTE	LV SD = LV EF <55% MV abnormal if it seemed to have moderate or severe mitral annular calcification, prolapse, flail, or at least moderately thickened leaflets or subvalvular apparatus according to accepted criteria. The aortic valve was considered stenotic if the valve was thickened or abnormally echodense with restricted leaflet opening in the representative views. The aortic valve was considered sclerotic if the valve was thickened or abnormally echodense but noted to have no restriction in leaflet opening. Regurgitation lesions were detected using CFM, physiologic and trace amount of regurgitation in the mitral and aortic positions was interpreted as normal
	Olesen *et al.* (9)	85%	89%	73%	94%					sTTE	LV SD = LV EF <40–50% visually for HHE

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Inexperienced users	Bansal et al. (33)	Onsite trained – 59.4%; remotely trained – 55.6%	Onsite trained – 98.4%; remotely trained – 98.3%			Overall for onsite trained 81.5%; remotely trained – 80%	Overall for onsite trained 99.7%; remotely trained – 100%			Only pts with major abnormalities found on HHE underwent further sTTE	LV SD = LV EF <55% Valvular lesions and their severity was based on a visual assessment. Severity of stenotic lesions was based on: thickness, calcification, leaflet mobility alongside adjacent chamber characteristics. The severity of regurgitant lesions was based on visual assessment of CFM (including width of vena contracta) and adjacent chamber size
	Gulič et al. (13)	Any: 84% Mod – 95%	Any: 92% Mod – n/a	Any: 16% Mod – 95%	Any: 84% Mod – 5%	AS: 90% MR: 77%	AS: 75% MR: 79%	AS: 38% MR: 50%	AS: 61% MR: 47%	sTTE	LV SD – purely visual assessment (no figures stated, severe LV SD = LV EF <30% visually) AS – visual (calcification and leaflet mobility), more than mild AS MR – visual assessment and CFM (intensity of signal)
	Mjøstad et al. (18)	92%	94%	80%	98%	AS: 76% AR: 82% MR: 71%	AS: 88% AR: 89% MR: 81%	AS: 74% AR: 69% MR: 71%	AS: 89% AR: 94% MR: 81%	sTTE	LV SD = LV EF <45% Valvular pathology and dysfunction was classified semiquantitatively as mild, moderate, or severe. Quantification of stenosis was based on the amount of calcification and the movement of the cusps/leaflets. Quantification of the regurgitations was based on the CF jet and size and function of the adjacent chambers
	Razi et al. (30)	94%	94%	97%	88%					sTTE	LV SD = LV EF <40%
	Ruddox et al. (19)	57% (45–68)	92% (87–95)	74% (61–84)	84% (79–89)	AS: 52% (37–68) AR: 30% (8–65) MR: 41% (26–58)	AS: 94% (89–97) AR: 99% (96–100) MR: 96% (92–98)	AS: 71% (52–85) AR: 75% (22–99) MR: 67% (45–84)	AS: 88% (82–92) AR: 96% (92–98) MR: 90% (85–93)	sTTE	LV SD = LV EF <40% AS – calcific aortic cusps/anulus + reduced opening, AR/MR – visual jet in accordance with ASE guidelines from 2003
GPs	Mjøstad et al. (20)	83.3% (66.4–92.7)	77.6% (64.1–87.0%)	69.4%	88.4%					sTTE	LV SD = sMAE <10 mm

Table 4 Sensitivities and specificities for WMA and pericardial effusion.

Who scanned?	Author	RWMA Sensitivity (95% CI)	RWMA Specificity (95% CI)	RWMA PPV (95% CI)	RWMA NPV (95% CI)	Pericardial effusion Sensitivity (95% CI)	Pericardial effusion Specificity (95% CI)	Pericardial effusion PPV (95% CI)	Pericardial effusion NPV (95% CI)	Comparator	Definitions
Experienced users	Andersen *et al.* (16)	97%	99%	92%	96%	89%	99%	100%	100%	sTTE	LV WMA –classed as present or not (?according to EAE guidelines) Any pericardial effusion
	Biais *et al.* (11)					91% (62–89)	96% (92–98)	67% (42–85)	99% (96–100)	sTTE	Each clinical parameter was recorded by using a qualitative approach considered positive, negative or undetermined (visual)
	Fukuda *et al.* (26) Acuson P10	88%	95%							sTTE	Regional LV WMA were defined as a segment with hypokinesis, akinesis, or dyskinesis
	Giusca *et al.* (14) Acuson P10	65.2%	89.5%	83.3%	76.5%					sTTE	LV WMA were either present or absent
	Khan *et al.* (28)	86%	97%	95%	91%	79%	99%	92%	98%	sTTE	Segmental wall motion was considered abnormal if there was at least one segment with lack of translational motion toward the centerline or lack of normal systolic thickening in accordance with standard echocardiography guidelines Pericardial effusion – either absent or present

	Michalski *et al.* (12)	In ICU 87.5%; In OPD 94.7%	In ICU 95%; In OPD 96.8%	In ICU 77.8%; In OPD 94.8%	In ICU 97.6%; In OPD 96.8%					sTTE	Segmental LV function was visually assessed and dichotomised as normokinesis or abnormal wall motion (hypokinesis, akinesis or dyskinesis)
	Phillips *et al.* (32)					89%	95%	62%	99%	sTTE	Pericardial effusion defined as excess fluid within the pericardial space
	Ruddox *et al.* (19)	76% (66–84)	88% (82–92)	79% (69–86)	86% (80–91)	45% (24–68)	95% (92–98)	43% (23–66)	96% (92–98)	sTTE	LV WMA Pericardial effusion (>5 mm fluid in end diastole)
Nurses (no experience)	Graven *et al.* (22)					91%	56%	74%	82%	sTTE	Pericardial effusions: 1) not present, 2) insignificant if the maximum dimension of each measurement was 5 mm, 3) moderate (5–14 mm) and 4) large if maximum dimension of at least one measurement was 15 mm

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Table 5 Sensitivities and specificities for AAA & IVC.

Who scanned?	Author	AAA Sensitivity (95% CI)	AAA Specificity (95% CI)	AAA PPV (95% CI)	AAA NPV (95% CI)	IVC Sensitivity (95% CI)	IVC Specificity (95% CI)	IVC PPV (95% CI)	IVC NPV (95% CI)	Comparator	Definitions
Experienced users	Andersen *et al.* (16)	100%	100%	100%	100%					sTTE	AA classed as AAA if >35 mm
	Biais *et al.* (11)					85% (64–96)	100% (97–100)	97% (78–100)	98% (93–99)	sTTE	Dilated IVC = End-expiratory diameter >23 mm and/or less than 50% collapse during inspiration
	Khan *et al.* (28)					93%	98%	98%	95%	sTTE	Dilated IVC = End-expiratory diameter >21 mm and/or less than 50% collapse during inspiration
	Ruddox *et al.* (19)					37% (20–58)	79% (63–83)	46% (25–67)	73% (60–83)	sTTE	IVC in inspiration - reported as normal, collapsed or dilated (measurements not specified)
Nurses (variable experience)	Dalen *et al.* (21)					72%	98%	93%	90%	sTTE	Dilated IVC = End-expiratory diameter >21 mm and a collapsibility index <35%

protocol for identification of cardiogenic dyspnoea has been well validated in two studies (15, 24) and can be a useful tool in clinical practice. Diagnostic parameters achieved with HHE by experts and non-experts are relatively high. For LV SD, our meta-analysis suggests that the experts' performance is superior to non-experts. As for AS, AR and MR, the data are very limited to draw any conclusions. Heterogeneity of patient populations, HHE scanner training (both existing and specific to the study), study and scanning protocols are highly heterogeneous making the data difficult to compare side by side. High-quality studies with robust study protocols are needed to assess: (1) the length of training required to safely use HHE; (2) diagnostic parameters in the hands of novices and training longevity; (3) the diagnostic values of HHE in general practice for more comprehensive HHE scans of the heart.

Device and terminology used

The terminology used in the literature to describe such devices – 'mini', 'mobile', 'hand', 'pocket' – is highly heterogeneous, making systematic literature searches difficult. This is reflected in our initial search, where nearly 50% of selected articles were later excluded because the devices featured were hand-carried, not hand-held. We suggest that a hand-held or pocket imaging device (PSID) should weigh <725 g (the weight of the Acuson P10 and the weight of most portable tablet computers) – allowing easy transportation from bedside to bedside.

Furthermore, to make pooling of data easier for future researchers we suggest using the terminology: pocket-sized imaging device (PSID), HHE or HHU when featuring a device that is truly hand-held.

What is a comprehensive HHE scan?

A scan using HHE is quick, and, given limitations of functionality associated with miniaturisation, cannot be as comprehensive as sTTE. In this study, we use the term comprehensive for any scan featuring LV assessment (size and function) and valvular function in at least PLAX, PSAX and at least three apical views as the majority of studies featured use this protocol. We suggest that ideally a truly comprehensive HHE scan would also include a quick visual RV, IVC assessment as well as a pericardial effusion screen and hence feature a subcostal view. This would be a simplified, 2D version, of the sTTE assessment and should be extensive enough to avoid missing obvious RWMA and valvular abnormalities adding no more than 4.8 min to the clinical encounter.

HHE benefits to clinical practice

For the expert clinician, HHE remains inferior to sTTE because of limited functionality. However, it is more accessible and portable and augments the standard physical examination. Cardiologists using HHE are able to detect more LV/RV SD and valvular pathology compared with full clinical examination including auscultation using a stethoscope (35). Agreement of HHE with sTTE in some studies is >90%, and the overall diagnostic metrics are similarly high (sensitivity 95%, specificity 83%) and are even higher for patients with underlying co-morbidities (sensitivity 98% and specificity 89%) (25).

HHE can be used by doctors (32) and nurses (21, 22) to detect pleural effusions with greater sensitivity and NPV than chest radiography (22, 24). This may aid the management of patients presenting with similar clinical features (e.g. dyspnoea), can help detect heart failure and guide management (22).

Given the high sensitivity of ultrasound, HHE can correctly change clinical diagnoses (36, 37) and has been shown to have a positive impact on 55% of patient cases (changing primary diagnosis in 16% of cases) (17). Even when used in suboptimal conditions, such as in the ED, the ability to obtain interpretable images remains high, as does agreement with sTTE for the detection of gross abnormalities such as LV/RV SD, IVC size and pericardial effusions (11).

Downstream modelling has shown a reduction in cost and length of hospital stay. Cost reduction with HHE is also seen when HHE is used in addition with other standard hospital tests such as ECG (25). This has been confirmed in a UK setting (38). Although users of HHE should be aware that lower feasibility and image quality is achieved when examining abdominal structures as compared to the cardiac structures (16, 17, 28).

Are inexperienced HHE users just as good as experienced users?

HHE devices appear 'user friendly' and can be used by novice users to acquire images effectively even after <1 h of training (39). However, image interpretation requires longer training. In one study, despite relatively strong correlations with sTTE ($r \geq 0.83$) for cardiac and abdominal pathologies, inexperienced users over- and underestimated some of the pathologies by at least one grade (18). Michalski *et al.* showed that agreement for LV RWMA using HHE was significantly lower than that obtained by an experienced cardiologist, however,

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Table 6 Sensitivities and specificities for all other pathologies detected.

Who scanned?	Author	Diagnostic parameters for HHE				Comparator	Definitions
		Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)		
Experienced users	Di Bello *et al.* (10)	Overall: 94%	Overall: 88%	Overall: 92%	Overall: 86%	Final diagnosis established by sTTE only in 124 pts	Overall metrics (RV and LV SD, LVH, WMA, valvular pathology) (graded visually by valve morphology, movement, presence of regurgitation and size of adjacent chamber)
	Biais *et al.* (11)	LVH: 77% (58–89) RV dilatation: 59% (39–77) IVC: 85% (64–96) Pericardial effusion: 91% (62–89)	LVH: 97% (92–99) RV dilatation: 98% (94–99) IVC: 100% (97–100) Pericardial effusion: 96% (92–98)	LVH: 83% (64–93) RV dilatation: 87% (62–96) IVC: 97% (78–100) Pericardial effusion: 67% (42–85)	LVH: 95% (90–98) RV dilatation: 93% (87–96)) IVC: 98% (93–99) Pericardial effusion: 99% (96–100)	sTTE	RV dilatation was defined by a diastolic ventricular ratio of >0.6 when measured in the A4C Each clinical parameter was recorded by using a qualitative approach considered positive, negative or undetermined (visual)
	Furukawa *et al.* (27)	AS-related events: 95%	AS-related events: 69%	AS-related events: 43%	AS-related events: 98%	AS-related events	Diagnostic values for aortic valve visual score ≥3 to predict for AS-related events (cardiac death or AV replacement)
	Giusca *et al.* (14) Acuson P10	LVH: 55.5%	LVH: 100%	LVH: 100%	LVH: 91.5%	sTTE	LVH was defined as IVSd >10 mm
	Kajimoto *et al.* (24)	MR or TR ≥ moderate: 92.4% IVC collapsibility <50%: 83% LV EF <40%: 26.4% Lung ultrasound: 96.2% LCI ultrasound: 94.3%	MR or TR ≥ moderate: 81% IVC collapsibility <50%: 81.1% LV EF <40%: 86.5% Lung ultrasound: 54% LCI ultrasound: 91.9%	MR or TR ≥ moderate: 87.5% IVC collapsibility <50%: 86.3% LV EF <40%: 73.7% Lung ultrasound: 75% LCI ultrasound: 94.3%	MR or TR ≥ moderate: 88.2% IVC collapsibility <50%: 76.9% LV EF <40%: 45.1% Lung ultrasound: 90.9% LCI ultrasound: 91.9%	Final consensus diagnosis by two cardiologists and one pneumonologist based on all available hospital tests (bloods, examination, ECG, CXR)	Diagnostic parameters for detection of AHFS (and differentiating it from a pulmonary cause of chest pain/dyspnoea) using HHE with the criteria on the left Lung, cardiac IVC (LCI) protocol described in detail in the original article
	Kimura *et al.* (29) Acuson P10	EPSS >1 cm: 47% (24–71)	EPSS >1 cm: 98% (87–100)			sTTE	LV SD – present when the anterior leaflet of the mitral valve did not encroach upon the left ventricular outflow tract in diastole (separation (EPSS) was greater than 1.0 cm in early diastole, which approximates a LV EF <55%)
	Kitada *et al.* (25)	Overall: 94% Low-risk group pts: 85% High-risk group pts: 98%	Overall: 83% Low-risk group pts: 76% High-risk group pts: 89%	Overall: 83% Low-risk group pts: 76% High-risk group pts: 94%	Overall: 91% Low-risk group pts: 85% High-risk group pts: 95%	sTTE	Overall metrics (LV SD, LV WMA, LVH, chamber size, valvuar pathology) (AR, MR, TR), dilated ascending aorta, pericardial effusion

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	Phillips *et al.* (32)	Cardiomegaly: 100% LA enlargement: 85%	Cardiomegaly: 51% LA enlargement: 81%	Cardiomegaly: 58% LA enlargement: 84%	Cardiomegaly: 100% LA enlargement: 83%	sTTE	Cardiomegaly defined subjectively if the LV did not fit in the scanning screen at 14 cm depth and by taking into account a subjective assessment of EF; LA enlargement defined if the LA was greater dimension than the aorta with HHE. sTTE (comparator used different definitions – not stated)
	Sforza *et al.* (15)	Cardiac dyspnoea: 81.4% (61.2–92.3)	Cardiac dyspnoea: 95.1% (82.2–99.2)	Cardiac dyspnoea: 91.7% (71.6–98.6)	Cardiac dyspnoea: 88.6% (74.6–95.7)	Clinical diagnosis	Cardiac dyspnoea defined by the presence of (interstitial oedema (presence of at least 3 B-lines) OR pleural effusion) AND (LV EF<40% OR dilated IVC (>2 cm))
	Skjetne *et al.* (17)	Overall: 97%	Overall: 93%	Overall: 93%	Overall: 87%	sTTE	Overall metrics for at least a moderate degree of the following pathologies: LV SD, RV SD, chamber size, valvular pathology, aortic aneurysm, pericardial effusion
Inexperienced users	Bansal *et al.* (33)	Overall for all major lesions: • For onsite trained physicians: 59.1% • For remotely trained physicians 55.6%	Overall for all major lesions: • For onsite trained physicians: 96.8% • For remotely trained physicians: 98.3%			Only patients with major abnormalities on HHE underwent sTTE (HHE in the hands of experts served as the reference in the other cases)	Major abnormality was considered when any of the following was detected: valvular regurgitation of moderate or greater severity, any valvular stenosis, all CHDs (except bicuspid aortic valves in the absence of any other associated significant abnormality), any LV systolic dysfunction or wall motion abnormality, and any other moderate or severe abnormality (e.g., moderate aortic root dilatation, moderate LV hypertrophy)
	Gulič *et al.* (13)	LVH: 83%	LVH: 58%	LVH: 64%	LVH: 35%	sTTE	Visual assessment of LVH
	Michalski *et al.* (12)	Overall: In ICU 83.3%; In OPD 95.8%	Overall: In ICU 88.9%; In OPD 84.7%	Overall: In ICU 45.4%; In OPD 94.7%	Overall: In ICU 98%; In OPD 96.7%	sTTE	A comprehensive assessment of LV function, WMA and IVC, valvular (AV, MV and TV) assessment and detection of pericardial effusion
	Mjøstad *et al.* (18)	RV SD: 40%	RV SD: 97%	RV SD: 57%	RV SD: 94%	sTTE	Atrioventricular annular excursion, RV dilatation and diastolic shift to the left IVS was included in the judgement of RV SD

(Continued)

Table 6 Continued.

Who scanned?	Author	Diagnostic parameters for HHE				Comparator	Definitions
		Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)		
GPs	Bornemann *et al.* (31)	LVH: 73% (59–87) (for GP >35 exams – 89%)	LVH: 75% (64–86) (for GP >35 exams – 67%)	LVH: 63% (48–77) (for GP >35 exams – 67%)	LVH: 83% (73–92) (for GP >35 exams – 80%)	sTTE	LVH was defined as LVMI 95 g/m² for women and 115 g/m² for men
Nurses (variable experience)	Dalen *et al.* (21)	Any pleural effusion – 92% Significant pleural effusion – 93%	Any pleural effusion – 99% Significant pleural effusion – 100%	Any pleural effusion – 97% Significant pleural effusion – 100%	Any pleural effusion – 97% Significant pleural effusion – 98%	sTTE	Pleural effusion detection protocol can be found in the original article. The extent of the effusion was measured just medially to the protruding edge of the lower lung lobe
Nurses (no experience)	Graven *et al.* (22)	Pleural effusion: 98%	Pleural effusion: 70%	Pleural effusion: 93%	Pleural effusion: 89%	sTTE	Pleural effusions: (1) not present, (2) insignificant (costodiaphragmatic angle only), (3) moderate if the PLE separated the diaphragm and the lung with a maximum distance between these two organs 30 mm and (4) large if this maximum distance was 30 mm

A4C, apical 4-chamber; AA, abdominal aorta; AAA, abdominal aortic aneurysm; AHFS, acute heart failure syndrome; AR, aortic regurgitation; AS, aortic stenosis; AV, aortic valve; CHD, coronary heart disease; EPSS, e-point septal separation; ICU, intensive care unit; IVC, inferior vena cava; IVSd, interventricular septal end diastole; LA, left atrium; LCI, lung-cardiac-inferior vena cava; LV EF, left ventricular ejection fraction; LV SD, left ventricular systolic dysfunction; LV, left ventricle; LVH, left ventricular hypertrophy; LVMI, left ventricular mass index; MR, mitral regurgitation; MS, mitral stenosis; MV, mitral valve; OPD, outpatient department; RV SD, right ventricular systolic dysfunction; RV, right ventricle; sTTE, standard transthoracic echocardiography; TR, tricuspid regurgitation; TV, tricuspid valve; WMA, wall motion abnormalities.

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remained high for more straightforward assessments such as LV SD (12). Residents' accuracy is higher for detecting extremes of LV SD (i.e. LV <30% and LV >50%) compared to moderate degrees of pathology (30). Furthermore, Gulič *et al*. showed that there was no significant difference in detection of severe pathology or some moderate valvular (AS, MR) pathologies by a newly trained medical resident using HHE as compared with a cardiologist (13). Our meta-analysis shows that experts detect LV SD using HHE more accurately than non-experts, which is not the case for AS, AR and MR. The former finding is the most expected and we speculate the valvular pathology analysis is hampered by the lack of studies reporting diagnostic parameters that we could extract and pool. Furthermore, heterogeneity is high across all the analyses.

Another use of HHE for the non-expert could be screening for pathologies that need fast-tracking for sTTE (13, 27). This would be extremely useful for GPs who are consulted by large numbers of elderly patients with breathlessness in whom systolic murmurs are detected, to screen for severe AS and severe LV SD. Currently, there is very limited evidence for the diagnostic utility for screening in the community using comprehensive HHE assessments. The use of HHE has been limited to measurements of LV hypertrophy (31) and LV SD using sMAE (20). However, given that such specific measurements can be obtained accurately by GPs, further studies assessing a broader range of pathologies are possible. Screening in the community by sonographers can detect significant pathologies (40). Given recognised shortages in highly skilled sonographers, training of GPs in this area may improve echocardiography uptake and request quality to the local echo department (34, 41, 42). The practicalities of re-imbursement for scans in primary care would need to be considered.

Training for inexperienced users: how much is enough?

The amount of training required for a user to achieve competence in HHE must partly be related to the type of assessment they are required to perform. The data presented in this review are too heterogeneous to draw any conclusions. The design of some studies implies adequate performance can be learned over some hours of training. In others, a number of days were required (18) or a minimum number of scans (12). Previously we have reported that even medical students can be taught to use HHE effectively (especially for LV SD) in under 10 h (43). It seems likely that the more time is spent performing HHE, the better the diagnostic accuracy. This is supported by studies of physicians (19) and nurses (21, 22). High-quality studies are needed to determine the threshold allowing users to practise under supervision, and then independently. Furthermore, research is needed on the retention of skill, and how quickly proficiency is lost if the skill is not practised (44).

Diagnostic criteria for HHE and future directions

We argue for the production of a guideline document specifically directed at HHE that contains recommended programmes of training, protocols for imaging and criteria for detection of pathology. Existing standards for detailed assessment make use of functions, such as spectral Doppler, that HHE lacks, and may not take into account the relative inexperience of the potential user of hand-held devices. Without such unifying recommendations there are likely to develop substantial differences in practice, quality and reliability between centres and individual users. Taking LV function as an example, is a purely visual assessment sufficient or does measurement using sMAE (20) or fractional shortening (26) add extra clinically important information when derived through HHE? What pathologies might trigger a more detailed urgent sTTE assessment? Given the reliability of HHE, what therapy might be started based on HHE findings alone.

Some argue that non-cardiologists should be trained as rigorously as cardiologists with respect to echocardiography as its use has the potential to change clinical management. Yet less highly trained non-experts should be capable of performing short screening studies (13, 18), answering clinical questions in a binary fashion to pre-specified clinical questions (45). As more HHE studies emerge using short training programmes and are tested and validated, those aspects of specific point of care echocardiography training programmes that are effective in teaching, learning, assessment and retention of skills may become more apparent (46, 47). As HHE becomes more commonly practised in acute and general medical specialties, the skill may become accepted as one of the clinical skills taught in medical school.

Limitations

The data are highly heterogeneous and tested in different settings, using different cohorts of patients. Furthermore, >40% of the studies originating from Europe came from Norway and some of them came from the same study

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group. Our meta-regression analysis suggests that the larger the studies, the poorer the user performance to detect LV SD. Furthermore, the funnel plots show that the findings from smaller studies are more enthusiastic in terms of outcomes or that there is an element of publication bias.

Conclusions

HHE can be used in the hands of experts and inexperienced users alike, although with a reduced diagnostic accuracy. It is a safe and effective screening tool for pathology and has greater diagnostic utility compared with physical examination for the detection of LV SD and valvular pathology. HHE can confirm and alter patient management in the hospital setting. There is evidence that it can provide a useful screening tool and 'gatekeeper function' for sTTE. Precise description of the diagnostic reliability of HHE is hampered by the heterogeneous nature of the various published studies. Further research with rigorous training protocols using truly hand-held devices is needed to evaluate its true potential.

Supplementary data
This is linked to the online version of the paper at https://doi.org/10.1530/ERP-18-0030.

Declaration of interest
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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