Garrett Newton Andersen

Point-of-care pocket-size ultrasonography - bringing the diagnosis back to the bedside

Thesis for the degree of Philosophiae Doctor

Trondheim, June 2015

Norwegian University of Science and Technology
Faculty of Medicine
Department of Circulation and Medical Imaging (ISB)

Nord-Trøndelag Health Trust
Levanger Hospital
Department of Medicine

NTNU – Trondheim
Norwegian University of
Science and Technology

NTNU
Norwegian University of Science and Technology

Thesis for the degree of Philosophiae Doctor

Faculty of Medicine
Department of Circulation and Medical Imaging (ISB)

Nord-Trøndelag Health Trust
Levanger Hospital
Department of Medicine

978-82-326-0924-6 (print)

978-82-326-0925-3 (digital)

1503-8181

Doctoral theses at NTNU, 2015:134

Printed by NTNU Grafisk senter

Norsk Tittel: Lommeultralyd – flytting av diagnostikken tilbake til pasientens sengekant

Sammendrag:
Legegjerningen har gjennomgått filosofiske og teknologiske forandringer i takt med samfunnet for øvrig. Praksis har endret seg dramatisk i løpet de siste 150 årene. Blodprøver, EKG, ultralyd, røntgen, CT, MR og gentesting har medført en betydelig bedring av vår diagnostiske treffsikkerhet, samtidig som vi diagnostiserer sykdommer på et tidligere stadium. Dessverre har den kliniske undersøkelsen vært offer for disse fremskrittene. Avansert bildediagnostikk foregår nå oftere på et rom langt unna pasienten, av leger som aldri har møtt eller kommer til å møte pasienten.

Til tross for disse teknologiske fremskrittene viser obduksjonsstudier at det fremdeles gjøres store diagnostiske feil hos opptil 30% av pasienter. Dette kan være et resultat av fallende ferdigheter i klinisk undersøkelse. Lommeultralyd utført ved pasientens sengekant har potensiale til å snu denne trenden. Lommeultralyd gjør det usynlige synlig og lar den behandlende lege, som kjenner pasienten best, se med egne øyne hva som feiler pasienten der og da.

Arbeidet består av 4 delstudier. Studie 1, 2 og 3 ble utført ved medisinsk avdeling ved Sykehuset Levanger, der nyinnlagte pasienter ble undersøkt med lommeultralyd av vakthavende lege. I Studie 1 undersøkte kardiologer, som er erfarne brukere av ultralyd, pasienter med lommeultralyd. Man fant godt samsvar med referansemetoden, både for mål på hjertets funksjon og anatomiske strukturer. I Studie 2 og 3 ble pasienter undersøkt av leger i spesialisering med varierende, men begrenset erfaring i ultralyd. Det ble funnet god til moderat samsvar med vurderingene gjort av erfarne kardiologer og med avansert utstyr. Ved bruk av lommeultralyd hos nyinnlagte pasienter fant man klinisk nytte hos 1/3 av pasientene (diagnosen endret, verifisert eller påvist viktig tilleggsdiagnose). I Studie 4 ble 30 medisinstudenter utstyrt med lommeultralyd i forbindelse med kliniske utplassering på sykehus. Studentene klarte å fremstille tilfredsstillende bilder hos mer enn 74% og stille riktig diagnose hos disse i over 93% av tilfellene.

Studiene konkluderer med at lommeultralyd er lett å bruke. Videre gir undersøkelsen raske, pålitelige og nøyaktig svar som er av klinisk nytte for en stor andel av pasientene. Nytteverdien er imidlertid avhengig av brukerens ekspertise.

Navn kandidat: Garrett Newton Andersen
Institutt: Institutt for sirkulasjon og bildediagnostikk, DMF, NTNU
Veiledere: Førsteamanuensis Bjørn Olav Haugen, Institutt for sirkulasjon og bildediagnostikk, DMF, NTNU, Forsker Håvard Dalen, Institutt for sirkulasjon og bildediagnostikk, DMF, NTNU og Professor Hans Torp, Institutt for sirkulasjon og bildediagnostikk, DMF, NTNU,

Ovennevte avhandling er funnet verdig til å forsvares offentlig
for graden PhD i Medisinsk teknologi.
Disputas finner sted i Auditoriet, Medisinsk teknisk forskningssenter
Torsdag 04.06.15, kl 10:15 og 12:15

Content

"If I have seen further it is by standing on the shoulders of giants." Sir Isaac Newton (1643-1727)

Aknowledgements

This work was financed by the Centre for Researched based Innovation, Medical Imaging Laboratory (MI Lab), Faculty of Medicine, NTNU and Levanger Hospital. Bjørn Olav Haugen, Department of Circulation and Medical Imaging, NTNU, was my main supervisor and co-supervisors were Håvard Dalen and Professor Hans Torp from the Department of Circulation and Medical Imaging, NTNU.

I appreciatively acknowledge the contribution of all my supervisors, who have each contributed in their own synergistic way to my thesis. Bjørn Olav is a seasoned researcher and fathered the medical student study. He has been my guide into the world of medical research, pointing out trapdoors along the way and showing me the correct paths when I was lost. Håvard introduced me to clinical research and was the mastermind behind the Levanger studies. He has on many occasions doubled as our statistician and awed us with his ability to crunch numbers and see the flip side of every result. Håvard has also been one of my most valuable mentors in clinical medicine and cardiology and amazes us all with his tremendous working capacity. Both Håvard and Bjørn Olav have always been approachable and positive, usually available around the clock and have provided me with excellent feedback, assistance and enthusiasm. I´m profoundly grateful for all the help and insight they have given me into the world of research and clinical practice. Hans has been my technical supervisor, and has made valuable contributions with his abundance of expertise in ultrasound technology, then and now.

Thank you to my co-authors; Ole Christian Mjølstad, Torbjørn Graven, Øyvind Salvesen, Olaf Kleinau, Kyrre Skjetne, Øystein Olsen and Anne Viset, for their valuable input into this work.
In particular, thanks to Øyvind S for being an excellent statistician and team player. A to special thanks to Ole Christian, my fellow PhD student for being there to share in the ups and downs along the way.

Thanks to all the participating doctors, nurses, and secretarial staff at Levanger hospital for their invaluable assistance with the inclusion and data collection for this study and to the medical students who volunteered to participate in the final study and the faculty of medicine, NTNU for accommodating our requests. The cooperation and goodwill of Levanger Hospital has been essential in the running of our clinical trials and for allowing me to take a PhD. Jon Hjalmar Sørbøe, chief of medicine and Øystein Sende, clinic manager deserve a huge thanks for understanding the importance of research and allowing me to combine it with my clinical work. Thanks to the rest of my colleagues for all I´ve learned outside of cardiology and putting up with, silently or not, my absences.

A special thanks to the cardiologists at Levanger Hospital; Torbjørn Graven the chief of cardiology, Håvard Dalen, Olaf Kleinau, Kyrre Skjetne and Bjørnar Klykken for great teamwork, teaching me good clinical cardiology and for all the understanding they have shown when being left short-handed. Particularly, thanks to Torbjørn for all his experience and clinical know-how, Håvard Dalen for his painstaking attention to detail and Olaf Kleinau who first taught me echocardiography.

Thanks to my mother for teaching me to love books, to my father for teaching me that if anything is worth doing, it is worth doing properly. And to both my parents for all their support and always telling me I can do anything I want as long as I put my mind to it. Also thanks to them on behalf my co-authors and myself for their expertise in proofreading our English manuscripts.

Thanks to my grandparents, Mormor and Grandpa, for showing me the nuances in life through art and philosophy and for teaching me to question the assumed truths.

Thank you to my beautiful partner Ina, for bringing order to chaos and seeing me through the final stages of my work with patience and understanding. Lastly, thanks to my gorgeous children William and Ella for all the joy they have given and continue to give.

List of papers

1. Andersen GN, Haugen BO, Graven T, Salvesen Ø, Mjølstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. *Eur J Echocardiogr* 2011; 12:665-670.

2. Mjolstad OC, Andersen GN, Dalen H, Graven T, Skjetne K, Kleinau JO, Haugen BO. Feasibility and reliability of point-of- care pocket-size echocardiography performed by medical residents. *Eur Heart J Cardiovasc Imaging* 2013; 14:1195-1202.

3. Andersen GN, Graven T, Skjetne K, Mjolstad OC, Kleinau JO, Olsen Ø, Haugen BO, Dalen H. Diagnostic influence of routine point-of-care pocket-size ultrasound performed by medical residents. Accepted for publication in the *J Ultrasound Med.*

4. Andersen GN, Viset A, Mjølstad OC, Salvesen Ø, Dalen H, Haugen BO. Feasibility and accuracy of point-of-care pocket-size ultrasonography performed by medical students. *BMC Med Educ* 2014; 14:156.

Selected Abbreviations

AA	Abdominal aorta
AAA	Abdominal aortic aneurysm
ASE	American Society of Echocardiography
CI	Confidence interval
EACVI	European Association of Cardiovascular Imaging
EF	Ejection fraction
IVC	Inferior vena cava
LA	Left atrium
LV	Left ventricle
MAE	Mitral annular excursion
NPV	Negative predictive value
PPV	Positive predictive value
RV	Right ventricle

Disease is very old, and nothing about it has changed. It is we who change, and we learn to recognise what was formally imperceptible. J.M. Charcot (1825–1893)

1. Introduction

1.0 Background

Much of the time-honed skills of physical examination are on the verge of being forgotten and what is forgotten is easily lost. Despite repeated appeals to revive this failing art, little has happened. The art of physical examination is endangered, largely due to advances in diagnostic tests and diagnostic imaging. Furthermore, patients are more often presenting earlier, with less obvious signs and symptoms of the disease from which they are suffering. The advent of pocket-size ultrasound used at the bedside, at the patients´ point-of-care, has the potential to save this valuable art from an early demise. An attempt to illustrate this is included in the coming chapters.

1.1 The physical exam – a brief history

-See, feel and listen! Inspection, palpation and auscultation, these pillars of modern physical examination stem from the time of the Pharaohs'. Hippocrates and his students continued this art of bedside examination, which has remained an essential part of medicine for more than two millennia (1, 2).

However by the 18th century a "dark age" of physical examination was at hand. Physical examination was largely abandoned by physicians in favour of a more scholarly and refined approach to illness. Close contact with patients was seen as beneath them, akin with manual labour, to be performed by the guild of barber-surgeons. Instead of touching their patients, physicians would listen to their woes, examine their excrement and prescribe lifestyle changes or homemade concoctions of dubious effect (3, 4).

The reawakening of physical examination was much inspired by Morgagni`s "*De sedibus et causis morborum"* (The Seats and Causes of Diseases) in 1761. It detailed post mortem studies and is seen by many as the birth of anatomical pathology. With the aid of his predecessors such as Boerhaave (1668-1738) he linked pathology and autopsy results to clinical medicine at the bedside and a new era of medicine emerged (1).

The famous diagnosticians of the 18 and 19th century followed. With Auenbrugger´s rediscovery of percussion and Laennec´s stethoscope slowly paving the way. Despite wide spread distrust amongst many physicians, the old principles of physical examination were gradually re-introduced and improved upon based on more scientific and objective observations and post-mortem findings. This has been by some been named the "Golden era" of physical examination (2).

Towards the end of the 19th century and early 20th century, the x-ray and electrocardiogram had emerged and found firm footholds in modern diagnostic medicine. From the middle of the 20th century, the advantages of biochemical tests and eventually ultrasound became increasingly apparent.

Over course of the last few decades yet another dark age of physical examination has apparently evolved. The physical examination skills of doctors have again declined as many modern physicians have disregarded the art of physical examination in favour of more modern and fashionable diagnostic techniques(5-10).

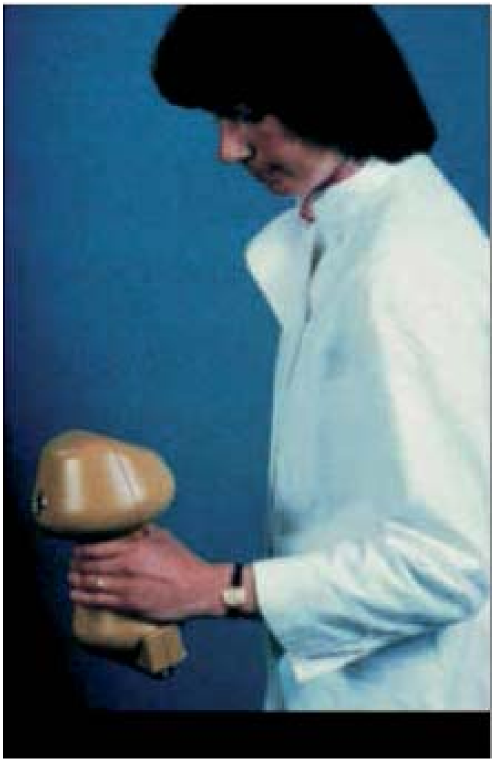
A bridge between traditional physical examination and modern diagnostics is needed. Point-of-care pocket-size ultrasound has the potential to bridge this gap and hopefully inspire a new "renaissance of physical examination" (2).

1.2. Ultrasound - then and now

Ultrasound in medicine and specifically cardiology began as a cumbersome tool of uncertain clinical applicability. Inge Edler and Helmuth Hertz pioneered much of the early use in the 1950s, but it was not until the late 60s and 70s that the actual clinical use of ultrasound became increasingly apparent (11). This was in large part due to the development of B-mode imaging, (allowing for real time visualization of anatomic structures), pulsed- and continuous wave Doppler and colour Doppler flow imaging (12-15). Several of the clinical applications of Doppler ultrasound in assessing and diagnosing valvular heart disease were described by Liv Hatle, Bjørn Angelsen and their group of researchers at Norwegian University of Science and Technology (NTNU) in Trondheim during the late 70`s (16-20). Since then the number of clinical applications of echocardiography has increased exponentially and is today the most widely used tool for assessing cardiac function and anatomy (21).

Despite Moore’s law predicting a doubling of the number of transistors in a dense integrated circuit every two years, the ultrasound machine remained large, heavy and cumbersome for several years to come (22). Instead of focusing on miniaturization, the constant advances in the integrated circuits predicted by Moore´s law were used to increase image quality and functionality of the ultrasound machines, including transitioning to the phased array probe, colour flow imaging and harmonic imaging. There were however, some early attempts at creating portable ultrasound devices with only limited success, such as the Minivisor in 1976 (Figure 1) (23). It took another 20 years before miniaturized products gained a foothold, eventually transforming these 200 kg colossus to pocket-size devices weighing less than 0.5 kg.

Figure 1.



The Minivisor. A portable echo apparatus developed around 1976.

Reproduced from (BOM N) with permission, Copyright © 2004, John Wiley and Sons

However, miniaturization and thereby increased flexibility comes at the cost of functionality. Miniaturized devices are either pocket-size, hand-held or laptop size, where the latter device usually contains more functionality and the former more flexibility. Recently the evolution of the smallest devices has accelerated and there are now several different pocket-size imaging devices (also known as PSIDs) available on the market. The two most studied are the Vscan® from GE Vingmed Ultrasound , Horten, Norway and the Acuson P10® from Siemens, Mountain View, Califorina, USA (24).

There are no head-to-head comparison studies of the different pocket-size ultrasound machines. They compare similarly in many regards, but the Vscan has the advantage of having a colour Doppler function. They have been shown to supply images of excellent quality, comparable even to that of high-end systems (25, 26). As the size of the ultrasound devices decreased so has the price, with most pocket-size ultrasound devices being available for less than 10000 USD.

Figure 2

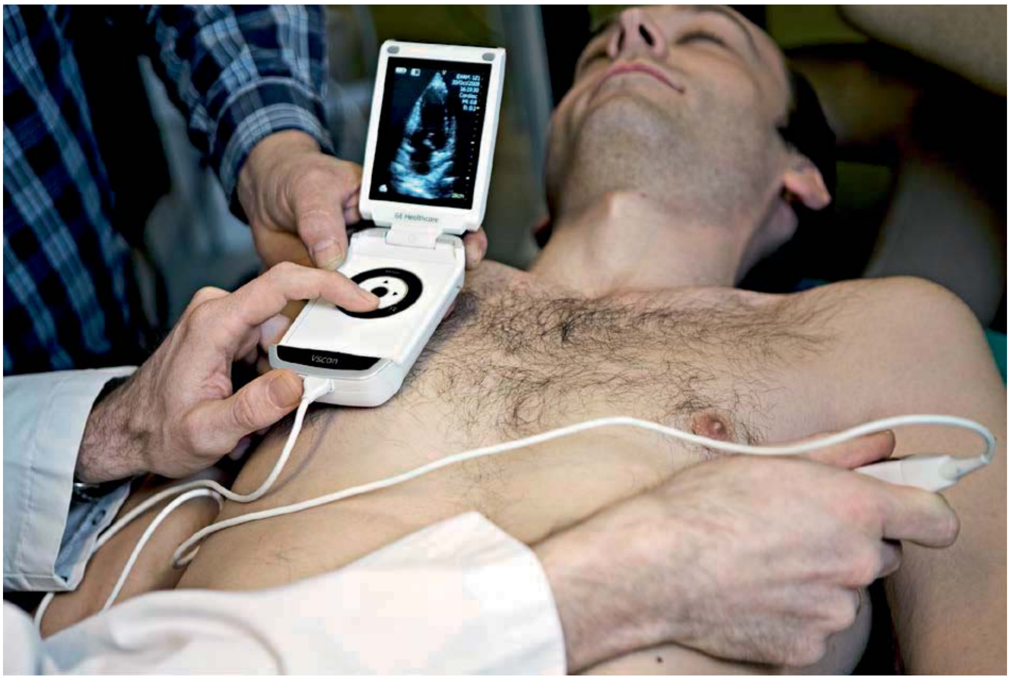


Photo: Geir Mogen/NTNU

1.3 Point of care

The miniaturization of ultrasound devices has helped lead the way to the term “point-of-care ultrasonography”, i.e. ultrasonography brought to the patient and performed by the provider in real time (27). This allows for the immediate acquisition of valuable diagnostic and procedural information that can be correlated to the patient’s signs, symptoms and situation. The invisible becomes visible (28). Moreover, it is easily repeatable and free from known adverse effects.

The practical applications of point-of-care ultrasonography are diverse and include; procedural guidance, focused diagnosis, screening and as a tool for medical education. Common bedside procedures such as vascular access, thoracocentesis, paracentesis and pericardiocentesis are easier and safer with ultrasound guidance (29).

The diagnostic aspect of point-of-care ultrasonography is generally more limited than formal ultrasonography. The exam is focused on certain areas or hypothesis, i.e. goal directed. Such as looking for specific causes of dyspnoea or chest pain such as pulmonary oedema, pulmonary embolism, pleural fluid, myocardial ischemia/infarction, cholecystitis and aortic dissection. Several diagnostic protocols have been developed over the years including FAST (Focused assessment with Sonography in trauma) and FATE (Focus Assessed Transthoracic Echo) (30, 31).

Point-of-care ultrasonography may provide the ideal platform for the screening of certain patients. It is cheap, quick and has a user-friendly interface. Health care providers can screen for serious diseases at an early, asymptomatic and treatable stage such as AAA and left ventricular dysfunction (32, 33).

Point-of-care ultrasonography can further aid in the teaching of anatomy and traditional physical examination skills to medical students with their ability to directly visualize organs and pathology at the bedside in real time (34, 35).

1.4 Training

The miniaturization of ultrasound devices has significantly increased the availability of diagnostic ultrasound devices and lowered the threshold for its use. It will be used more often, in different scenarios, testing diverse hypothesis by clinicians of differing expertise in ultrasonography. The accuracy and reliability of an ultrasound exam depends on the user. It is not feasible to make every clinician an expert ultrasonographer, but a certain degree of competency pertaining to the expected tasks should be established. Furthermore, the implications and limitations of pocket-size ultrasound findings need to be made clear to both the clinicians performing the examination as well as the patients receiving them.

The American and European associations of echocardiography/cardiovascular imaging have both published guidelines and recommendations relating to the use of hand-carried and pocket-size ultrasound devices. Both highlight that these miniaturized ultrasound devices should not replace high-end systems, but rather function as a supplement to the clinical examination (36-38). The European Association of cardiovascular imaging (EACVI, formerly known as the European Association of Echocardiography, EAE) states that expert echocardiographers do not need any training for the use of pocket-size ultrasound and conversely that non-experts should undergo a dedicated training program tailored to the expected clinical use (36, 38). The American society of echocardiography (ASE) recommends training for physicians without a minimum level II training in echocardiography and propose a curriculum of 3 separate core components, including didactic training, hands-on training and image interpretation (37). Recently the EACVI has launched their own EACVI Education Program for Pocket Size Ultrasound Devices (39). It is aimed at “all users of pocket-size ultrasound devices with the exception of cardiologists who are certified for transthoracic echocardiography according to national legislation”. This education program includes eight online courses covering basic echocardiography and cardiac anatomy as well as specific clinical scenarios. It also requires proof of hands on clinical practice with a pocket-size ultrasound device under supervision of an experienced echocardiographer in a hospital environment before certification.

1.5 Diagnostic performance

When introducing new diagnostic modalities to clinical practice it is imperative to know its accuracy and reliability. This is measured in different ways by differing statistical methods, and included below is a brief overview of the background for the most used statistical methods in data analyses of the diagnostic performance of pocket-size ultrasonography.

When a diagnostic tool is accurate it tells us precisely when a patient has the disease and when it does not, also referred to as true positives and true negatives. Unfortunately, diagnostic tools are seldom perfect in both ways. In clinical medicine there will always be a certain degree of inaccuracy. The test may report that a disease is present when it is not, i.e. a false positive result. This may lead to further inappropriate, possibly dangerous and costly testing and/or incorrect treatment with all the possible side effects and none of the benefits. Conversely, the test may report that a disease is not present when it in fact is, i.e. a false negative result. This can lead to missed diagnosis and the withholding of appropriate diagnostic test and treatment for the disease.

The overall accuracy of a test is the total of correct test results divided by the total correct and incorrect test results.

Accuracy = True positives + True negatives /Sum of tests

(True positives + False positives + True negatives + False positives)

Clinically: How many patients with and without disease will be found with the test?

A measure of the degree of true positives/negatives and false positives/negatives is given by a test's sensitivity and specificity.

Sensitivity = True positives/ True positives + False negatives = True positives / Diseased

Clinically: The chance of detecting patients with the disease by the test.

Specificity = True negatives /True negatives + False positives = True negatives / Healthy

Clinically: The chance of detecting patients without the disease by the test.

Sensitivity depends on the relationship between true positives and false negatives, thus a test with a high sensitivity has a high proportion of true positives, and therefore few false negatives. A test with high specificity has a high proportion of true negatives, and therefore few false. There is no perfect test with 100% sensitivity and specificity; instead, there is usually a trade-off between the two. Thus, by increasing the sensitivity of a test we will decrease it´s specificity and vice versa. The optimal cut-off value between sensitivity and specificity of a test will depend on whether we want to rule in or rule out a disease.

To better describe the implications of a positive or negative result the positive predictive values (PPV) and negative predictive values (NPV) are used. The PPV gives us the proportion of patients with a positive test result who actually have the disease, whilst the NPV gives us the proportion of patients with a negative test who do not have the disease. This is of course important in everyday clinical practice, but it is complicated by the fact that both the PPV and NPV depend on the prevalence of the disease in the specific population. A population with a high prevalence of disease will have a high PPV just because the chance of disease is so high. Conversely, in a population with a low prevalence of the disease the NPV will tend to be high. E.g., young athletes have a low incidence of AAA and the PPV of an abdominal ultrasound for detecting an AAA would be lower in this population, whilst the NPV would increase and the sensitivity and specificity would remain the same. The opposite would be expected in a sample of octogenarians with a history of coronary artery disease where we expect a high incidence of AAA.

PPV = True positives / True positives + false positives = Diseased with positive test / positive test results

Clinically: The proportion of patients with a positive test result that actually has the disease.

NPV = True negatives / True negatives + false negatives = Healthy with negative test / negative test results

Clinically: The proportion of patients with a negative test result that actually is healthy.

Table 1. Illustration of the relationship between sensitivity, specificity, positive and negative predictive values

	Disease positive	Disease negative	
Test positive	A. True positive	B. False positive	Positive predictive value = A/A + B
Test negative	C. False negative	D. True Negative	Negative predictive value = D/D + C
	Sensitivity = A/A + C	Specificity = D/D + B	Accuracy = A + D/A +B + C + D

Once the cut-off levels have been established it is mandatory to know how reliable the measurements are compared to gold standard. For this purpose correlation statistics may be used. Correlation is given as *r* (rho) with a range from -1 to 1. A negative denotation illustrates a negative correlation, and the strength of the correlation relates to the absolute number. An *r* value of 1 denotes a perfect correlation, an *r* value >0.8 denotes an almost perfect correlation, an *r* value of 0.61-0.8 denotes a substantial correlation, whilst an *r* ≤0.6 denotes a slight to moderate correlation. There are different ways of calculating the correlation depending on the data set. For continuous data Pearson's *r* is preferred, whilst Spearman's R is used for non-parametric and ranked data. Kappa values are also used to estimate correlation, but only for non-ranked categorical data.

These statistical tools are used in the analyses to more correctly judge the diagnostic performance, and thus, the place of the use of pocket-size ultrasound in clinical practice.

2. Aims

2.1 General aims

To study the feasibility, reliability, accuracy and clinical influence of point-of-care pocket-size ultrasonography in the hands of experts and non-experts.

2.2 Specific aims

- To study the reliability and feasibility of point-of-care pocket-sized echocardiography at the bedside performed by experts
- To study the reliability and feasibility of point-of-care pocket sized ultrasonography at the bedside performed by medical residents
- Investigate the potential benefit of adding goal-directed ultrasound examination performed by on-call medical residents using point-of-care pocket sized ultrasonography in patients admitted to a medical department
- Investigate whether medical students with minimal training were able to successfully acquire and interpret ultrasound images using a pocket-size ultrasonography as a supplement to their clinical practice

3. Material

Location:

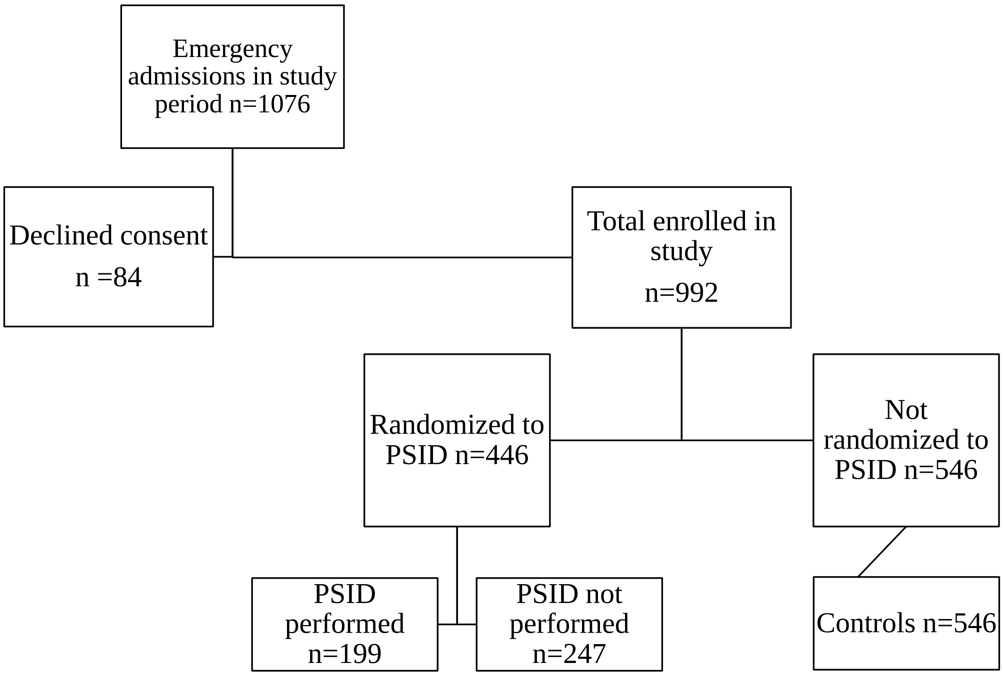
Studies 1, 2 and 3 were conducted through the Department of medicine, Levanger Hospital, Nord-Trøndelag Health trust, Norway. Levanger Hospital is a non-university hospital that provides healthcare services for a population of approximately 100,000.

Study 4 was conducted through The Faculty of Medicine at the NTNU and later at 7 regional hospitals between January-May 2012.

Population:

In Studies 1, 2, and 3 the patients were all emergency admissions and worked up in a standard manner by the admitting doctor and subsequently the medical team after admission. In Study 1 three experienced cardiologists included 108 patients between March-September 2010. All newly admitted patients to the medical ward present for the on-call cardiologist`s evening rounds were included. Studies 2 and 3 were conducted between the 4th of April and 23rd of June 2011. Of a total of 14 medical residents, 6 had been randomized by draw to participate in the study. Patients admitted on dates with an on-call medical resident randomized to perform the ultrasound examinations were included in the active arm. Of 446 available patients the residents included 199 of them (Figure 3).

Figure 3. Study Population and randomization



Flow chart illustrating the study population and randomization categories.
PSID; Pocket-size imaging device. Reproduced with permission from the American Institute of Ultrasound in Medicine.

In studies 1, 2 and 3, there was no exclusion criterion other than death or discharge before completed study protocol or withdrawal of consent. Patients were specifically not excluded due to poor image quality, previous illness or any other unspecified attribute that may result in a suboptimal examination. The basic characteristics of the study populations from the three studies are presented in Table 2 and 3.

Table 2. Basic characteristics of the 108 study participants in study 1

Variable	**Mean ± SD (range)**[1]
Age, years	69.1 ± 13.7 (20-92)
Women, N (%)	39 (36%)
Height, cm	172 ± 9 (146-189)
Body mass index, kg/m^2	27 ± 5 (17-44)
Systolic blood pressure, mm Hg	146 ± 32 (58-250)
Diastolic blood pressure, mm Hg	81.5 ± 20 (32-161)
Heart rate, bpm	78.7 ± 24 (29-145)
Atrial fibrillation, N (%)	22 (20%)
Prior hypertension, N (%)	39 (36%)
Prior diabetes, N (%)	18 (17%)
Prior myocardial infarction, N (%)	33 (31%)
Prior angina, N (%)	27 (25%)
Prior heart failure, N (%)	12 (11%)
Prior peripheral vessel disease, N (%)	13 (12%)
Prior stroke, N (%)	12 (11%)

[1]Data are presented as mean ± SD (range) unless otherwise specified.

Table 3. Basic demographics of the participants from Studies 2 and 3

Variable	PSID received n= 199	Randomized to PSID, but not received n = 247	p-value*	Control Group n = 546	p-value#
Age	64.8 ± 18.1 (17-98)	66.5 ± 19 (16-98)	0.34	67 ± 17,7 (16-97)	0.14
Women, n (%)	94 (47%)	112 (45%)	0.69	246 (45%)	0.60
Systolic blood pressure	144 ± 29 (74-245)	141 ± 27 (68-217)	0.33	145 ± 30 (65-237)	0.66
Diastolic blood pressure	75 ± 16 (24-120)	74 ± 16 (31-120)	0.54	76 ± 17 (33-152)	0.37
Body mass index (BMI)	26.4 ± 5.6 (12-45)	25.6 ± 5.1 (14.2-38.1)	0.58	26.2 ± 5.6 (14.4-51.6)	0.67
Pulse	83 ± 23 (40-160)	82 ± 20 (44-140)	0.80	83 ± 21 (26-195)	0.78
Temperature	37.2 ± 0.8 (35.3-40.3)	37.3 ± 0.9 (35-40.3)	0.67	37.2 ± 0.9 (35.1-40.9)	0.55
Atrial fibrillation	33 (17%)	29 (13%)	0.31	71 (15%)	0.51
Hypertension	67 (34%)	64 (26%)	0.07	154 (28%)	0.15
Diabetes Mellitus	38 (19%)	39 (16%)	0.36	97 (18%)	0.68
Myocardial infarction	33 (17%)	45 (18%)	0.65	88 (16%)	0.88
Angina pectoris	18 (9%)	30 (12%)	0.29	56 (10%)	0.63
Heart failure	20 (10%)	30 (12%)	0.49	73 (13%)	0.23
Peripheral vascular disease	7 (4%)	9 (4%)	0.94	32 (6%)	0.20
Cerebrovascular accident	35 (18%)	43 (17%)	0.96	81 (15%)	0.36
Malignancy	16 (8%)	38 (15%)	0.02	85 (16%)	0.008

PSID; Pocket-size imaging device. Data are presented as mean ± SD (range) unless otherwise specified. *p-value for difference between PSID examinations received and PSID randomized, but not received. # p-value for difference between PSID examinations received and control group. Reproduced from Paper 3 with permission from the American Institute of Ultrasound in Medicine.

In Study 4, 30 fifth year (of six) medical students volunteered to participate in the study. At the end of the study period and clinical placement, 21 medical students had included 211 patients (43% male, 38% female and 18% unrecorded sex). All patients over 18 years of age, encountered in-hospital or at outpatient clinics during the students' clinical placement periods were eligible for inclusion. The only exclusion criterion was lack of consent. 1 student did not hand in a completed logbook and a further 8 students did not perform any inclusions and were therefore excluded from the study. Each student included a median of 9 (± 8, range 1-27) patients.

4. Methods

4.1 Study design

Study 1, 2 and 3: In Study 1 point-of-care pocket-size ultrasound examination was performed by cardiologists experienced in echocardiography. In Study 2 medical residents with limited ultrasound experience performed point-of-care pocket-size ultrasound examinations. Study 3 was a prospective observational study on the same population, but this time examining the diagnostic influence of routinely adding a focused point-of-care pocket-size ultrasound examination performed by medical residents to standard care which included routine history taking, physical examination and relevant laboratory and imaging tests. In Study 1, newly admitted patients were examined by one of three cardiologists performing their regular evening ward rounds. In Studies 2 and 3, patients were examined by one of 6 participating medical residents. All pocket-size ultrasound findings were recorded and any suspected pathology was referred for subsequent formal reference imaging. Additionally a selected amount of reportedly normal findings were referred for reference imaging as controls.

Study 4: The thirty medical students that volunteered to participate were each given a personal pocket-size ultrasound to use as a supplement to their physical examination during their allocated hospital terms. The students performed patient inclusion and selection. They were required to hand-in a logbook along with their pocket-size ultrasound devices at the end of their hospital placements where they described basic patient characteristics and their own pocket-size ultrasound findings.

4.2 Training and education

Study1: No additional formal training or education was performed as the three participating doctors were all board certified cardiologists with an EAVCI advanced competence level in echocardiography and were familiar with the pocket-size ultrasound device.

Study 2 and 3: The medical residents received four hours of formal didactic lectures from a cardiologist and radiologist on the physics, pitfalls and limitation of ultrasound, as well as a theoretical map on how to perform the examinations. Normal and pathological findings were demonstrated. The focus was on scanning techniques, image acquisition and interpretation of the ultrasound images. They all had access to an in-house imaging library with illustrations of both anatomy and pathology including how to obtain similar views and images, as well as how to interpret them for clinical decision-making. Subsequently, they were encouraged to perform as many examinations as possible or at least 100 abdominal and cardiac examinations with a high-end, mobile or pocket-size ultrasound device prior to study start. During this time focus was on hands-on training. The residents were allocated personal supervisors experienced in ultrasonography/echocardiography and given access to the ultrasonography and echocardiography laboratory. The actual numbers performed prior to study start, including those performed before randomization, were median (interquartile range) 95 (80-225) examinations and median (interquartile range) 32.5 (20-85) examinations were supervised hands-on by a relevant specialist or advanced trainee.

Study 4: The medical students received 3 evenings (9 hours) of combined theoretical and practical training in the use and interpretation of ultrasound images. The theoretical training was given as short didactical lectures by relevant specialists (cardiologists and radiologists) and focused on basic ultrasound physiology, anatomy and examples of normal and pathological ultrasound images. The students were specifically trained to assess for pathology relevant in the immediate emergency care of patients. Practical, hands-on training was given by relevant specialists and advanced trainees, with students using their personal pocket-size ultrasound. Students were encouraged to perform at least 75 examinations prior to study start.

4.3 Pocket-size imaging device, the examinations and indications for reference imaging

The ultrasound examination in all four studies was performed bedside with a pocket-size imaging device; Vscan (version 1.1 and 1.2) (GE Vingmed Ultrasound, Horten, Norway). The device measures 135 × 73 × 28 mm and weighs 390 g, including the phased-arrayed probe. Two-dimensional grey scale and live colour Doppler imaging were obtained. The image sector for echocardiographic imaging is 75°. The bandwidth ranges from 1.7 to 3.8 MHz and is automatically adjusted. Storage and looping of a cardiac cycle are possible without ECG signal and looping of other structures is predefined and limited to 2 seconds. The device has separate modes optimized for cardiac and abdominal examinations. Patient identification was performed using voice recording and/or the automatically assigned examination number. All images and recordings were saved on the device’s micro-SD card and later transferred to a computer by commercial software (Gateway; GE Vingmed Ultrasound).

Study1, 2 and 3: A standardized examination protocol was used. The bedside (point-of-care) cardiovascular ultrasound examination was performed with patients in the left-lateral decubitus position, supine position or both. All measurements of dimensions were done on the pocket-size ultrasound device. Assessment of left ventricle (LV) global and regional function, right ventricle (RV) size and function, valvular anatomy and function, and the pericardium were done from parasternal long- and short-axis and apical four-chamber, two-chamber and long-axis views using grey scale and colour flow modes. LV and RV functions were classified by visual assessment as: normal/near normal, moderate dysfunction or severe dysfunction. Valvular pathology and dysfunction was classified semi-quantitatively as mild, moderate or severe. Pericardial effusion was classified as present or not. The size of the left atrium (LA) was measured online on grey-scale parasternal long-axis images and converted to semi-quantitative measures. An attempt was made to do the measurement of the LA at end-systole. The abdominal aorta (AA) and inferior vena cava (IVC) were assessed from the subcostal position. The AA was assessed distally to the bifurcation and classified as: no abdominal aortic aneurysm (AAA) present or AAA present, depending on whether the diameter exceeded 35 mm or not in Study 1 and 3 and 30 mm in Study 2. IVC diameter was measured end-expiratory within 2 cm from the right atrium orifice. With patients in a supine or upright position, the pleura was assessed from left and right thoracic dorsolateral views, and the amount of pleural effusion was classified as: no pleural effusion, small-to-moderate amounts of pleural effusion or significant pleural effusion (40).

The liver, gallbladder and kidneys were assessed from a supine position. The liver and gallbladder were classified as normal or abnormal. The kidneys were classified as normal, evidence of hydronephrosis or other pathology.

All patients with reported pathological findings were referred for standard reference imaging. Additionally, all patients admitted to the cardiology department in Study 1 underwent subsequent echocardiography regardless of the findings by pocket-size ultrasound. In Studies 2 and 3, the study committee daily selected 1-2 patients at random, with reportedly normal pocket-size ultrasound findings, to undergo reference echocardiography and/or abdominal ultrasound examinations to assess the degree of false negative findings. In order not to impede hospital workflow, radiologists responsible for reference imaging of patients with positive and negative findings were not blinded to the results of the pocket-size ultrasound examination. However, the cardiologists performing the high-end reference imaging procedures in studies 1, 2 and 3 were blinded to the results of the pocket-size ultrasound examination, but not to the data from the medical history or physical examination. For the analyses of the patients who underwent both echocardiographic and radiographic examinations, the radiologists' classifications of pleural effusion (CT or ultrasound) and the size of the abdominal aorta were preferred in cases with dual measurements.

Study 4. All patients were examined during the students allocated hospital terms. A standardized examination protocol was used. The bedside (point-of-care) ultrasound examination was performed with patients in the left-lateral decubitus, supine position or both. The left ventricular (LV) was assessed from the apical four-chamber view. They were instructed to assess for reduced LV function defined as mitral annular excursion (MAE) <10 mm (41-43), pericardial effusion, pleural effusion, lung comets, inferior vena cava (IVC) diameter and variation, hydronephrosis, bladder distension, gallstones, signs of cholecystitis, diameter of abdominal aorta (AA) and abdominal free-fluid. Pericardial effusions, IVC and

AA were examined from the subcostal position. Pleural effusions and lung comets were assed from the supine and/or upright position. No data for reference imaging was collected.

4.4 Data analysis

Pocket-size ultrasound recordings were transferred to a standard laptop or stationary PC using the Vscan Gateway software (GE Healthcare, Horten, Norway). The reference echocardiography recordings were transferred to the hospital database and analysed using EchoPAC PC, version BT 09 (GE Vingmed, Horten, Norway).

Study 1 and 2: The feasibility and reliability of point-of-care pocket-size ultrasound examination performed by cardiologists and medical residents was compared to high-end imaging performed by cardiologists and radiologists. The statistical analyses are more extensively described below.

Study 3: The diagnostic influence of point-of-care pocket-size ultrasound examination was assessed. Diagnostic corrections were made after examination with a pocket-size ultrasound at the patient´s bedside. All patients' diagnostics were judged in an end-point committee of relevant specialists. The committee members were blinded to the decisions of the other members. The diagnostic usefulness of pocket-size ultrasound examination was judged on an individual basis, using medical journals and considering all relevant diagnostic tests performed prior to examination with pocket-size ultrasound examination. The influence of pocket-size ultrasound examination was divided into the following categories: 1) The principal diagnosis was changed, 2) the principal diagnosis was confirmed, 3) an additional diagnosis important for in hospital treatment or follow-up was added, 4) an additional diagnosis which did not influence treatment or follow-up was made or 5) no change, verification or additional diagnosis was made. In case of disagreement (33 out of 199) the majority of the committee had the preference.

Study 4: The feasibility and accuracy of point-of-care pocket-size ultrasound examination performed by medical students was assessed. The students were required to hand-in a log of selected examinations including their own set diagnosis based upon pocket-size ultrasound examination. The specialists, 1 radiologists and 2 cardiologists, were asked to categorize the image acquisition of relevant organ as acceptable or unacceptable for clinical interpretation and then determine whether the set diagnosis of the acceptable images were correct or incorrect.

4.5 Statistics

All the statistical analyses were performed using SPSS for Windows/Mac (version 18.0 and 20.0, SPSS Inc, Chicago and IBM Corp. Armonk, NY) and R (version 2.13.1, R Development Core Team, Vienna).

Study 1, 2 and 3: The basic demographics are presented as mean ± standard deviation (SD) and range. Data not following a normal distribution were presented as median and (interquartile) range. The Mann–Whitney U test of independent samples was used for comparison of continuous variables between groups. Proportions between groups were analysed by chi-square statistics or Fisher's exact test. The Spearman's rho (r) was used for ranked non-parametric data when comparing pocket-size and the high-end echocardiographic or radiographic examinations. For comparison of continuous variables Pearson's rho (r) was used. Similarly, non-ranked, non-parametric data was analyzed by kappa statistics. Data are presented as r (95% confidence interval (CI)) with the 95% CI computed using bootstrapping.

In Study 3, logistic regression analyses were used to assess predictors of influence of the pocket-size ultrasound examinations. Change of the primary diagnosis or any diagnostic usefulness (change or verification of the primary diagnosis, or an important additional diagnosis) was used, as dependent variable, and age and cardiovascular risk factors were included as independent variables.

Study 4: Data not following a normal distribution were presented as median and (interquartile) range. For sufficiently large samples, logistic mixed model with random intercepts for students was used to examine estimate proportions. Clopper-Pearson estimates were used for small sample analyses. Sensitivity and specificity, negative and positive predictive value calculations were performed using relevant specialists as “gold standard”.

4.6 Ethics

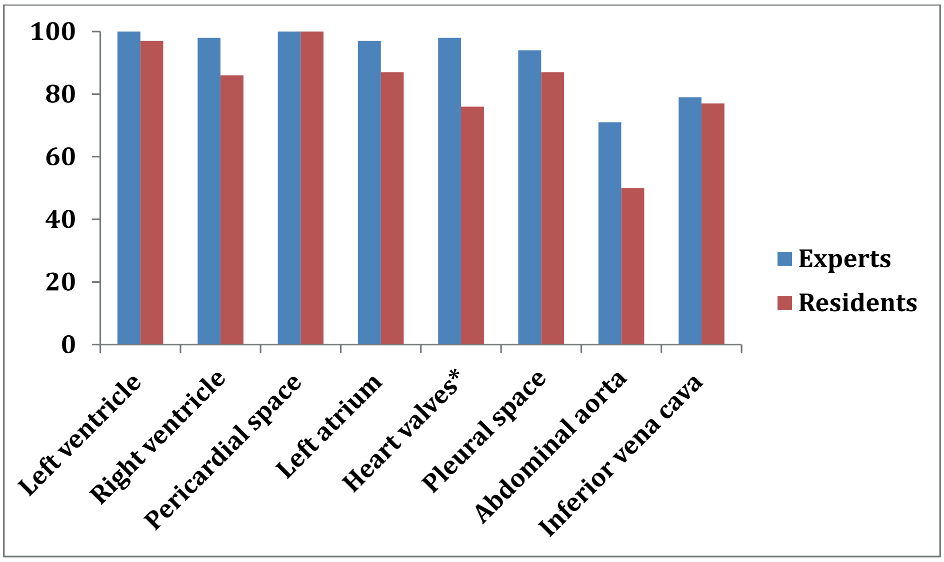
Written informed consent was obtained from all patients and all studies were conducted according to the Declaration of Helsinki. The Regional Committee for Medical and Health Research Ethics (REC) approved studies 1, 2 and 3. REC had no objections to Study 4 as this was deemed an integrated part of the medical curriculum and not subject to REC´s approval.

5. Summary of results

Study 1 and 2: In Study 1, the cardiologists used a median time of 4.2 minutes (range 2.3-13.0) for a pocket-size ultrasound examination of the cardiovascular system. Whilst the medical residents in Study 2 used a total of 10.6±4.4 minutes (range 3.2-32) for a complete exam above and below the diaphragm, specifically 5.7±2.7 minutes (range 1.6–18.3) and 4.7±2.7 minutes (range 1.2-12.9) for cardiovascular and abdominal exams, respectively. In

Study 1 the cardiologists showed high feasibility (≥ 98%) for cardiac structures such as the LV, RV, LA heart valves and pericardial space. Whilst feasibility for the greater vessels (AA and IVC) was lower at 71% and 79% respectively. Feasibility for assessing the pleural space was also high (94%). The medical residents in Study 2 showed a lower feasibility for some cardiac structures, such as the RV, LA and heart valves (86%, 87% and 76% respectively), but similar feasibility for the LV and pericardial space (≥ 97%). Assessment of the pleural space (95%) and IVC (77%) was also similar, but the residents showed reduced feasibility for assessing the AA (50%). The feasibility for assessing cardiovascular structures in studies 1 and 2 is presented in Figure 4.

Figure 4. Feasibility of cardiovascular structures in Studies 1 and 2.



Feasibility (%) of different cardiovascular structures by pocket-size echocardiography when the examination was performed by experts and residents. *All 4 valves by the experts, and all except the pulmonic valve in the resident study. Reproduced with permission from Ole Christian Mjølstad, NTNU.

The reliability, i.e. correlation, between the pocket-size ultrasound and high-end imaging was substantial to almost perfect for most indices in both Study 1 and Study 2 and is shown in Table 4. Specifically in Study 1 the cardiologists showed almost perfect correlation for global and regional LV function, RV size, pericardial and pleural effusions and AA (r = 0.95, 0.92, 0.85, 0.94, 0.89, 1.0, respectively). Almost perfect correlation was also found for aortic, mitral and tricuspid regurgitation ($r \geq 0.81$) and substantial correlation for aortic stenosis (r = 0.62). The degree of LA dilatation and IVC size and variability showed substantial correlation of r = 0.65 and 0.68). Study 2 showed lower, but still acceptable correlation when comparing measurements performed by the residents with reference imaging. The measurements performed by the medical residents showed almost perfect correlation for global LV function, pericardial and pleural space ($r \geq 0.83$). Substantial correlation was also seen for aortic calcification/stenosis and regurgitation (r = 0.67 and 0.68), whilst mitral and tricuspid regurgitation was moderate to substantial (0.53-0.61). The correlation for LA dilatation was similar to Study 1 (r = 0.61). Whilst assessment of the AA for detecting abdominal aortic aneurysms (AAA) was less robust than in Study 1, it still showed a substantial correlation with reference imaging by experts (r = 0.70). The sensitivity, specificity, positive and negative predictive values from studies 1 and 2 are presented together in Table 5.

Table 4 Correlations of semi-quantitative quantification of cardiovascular structure and function indices and abdominal pathology of pocket-size ultrasound and reference method when used by experts and non-experts.

	N total Expert/non-expert	N pathology Expert/non-expert	*r* Expert/non-expert	95% CI Expert/non-expert
Global LV function	108/129	35/26	0.95/0.83	0.90-0.99 /0.71-0.93
Regional LV dysfunction	108/129	35/22	0.92/0.60	0.83-0.98/ 0.39-0.78
Global RV function	106/115	10/10	0.85/0.44	0.65-1.0/ 0.10-0.72
LA size	107/117	69/68	0.65/0.61	0.52-0.76/ 0.48-0.72
Aortic calcification and stenosis	106/119	24/37	0.62/0.67	0.42-0.79/ 0.52-0.80
Aortic regurgitation	106/117	31/27	0.92/0.68	0.83-0.98/ 0.52-0.82
Mitral regurgitation	107/123	54/54	0.89/0.53	0.82-0.95/ 0.37-0.68
Tricuspid regurgitation	108/107	34/49	0.81/0.61	0.69-0.91/ 0.45-0.74
Pericardial effusion	108/131	9/4	0.94/0.86	0.78-1.0/ 0.57-1.00
Pleural effusion	85/151	14/20	0.89/0.83	0.74-1.0/ 0.67-0.94
Abdominal aorta	67/52	7/2	1.0/0.70	1.0/ 0.49-1.00
Inferior vena cava*	76/94		0.68/0.45	0.53-0.80/ 0.24-0.62
Kidneys	170	27	0.64	0.39-0.85
Liver and gallbladder ^	166	30	0.54	0.36-0.75

Unless otherwise specified data is presented as Spearman's rank correlation coefficient (*r*) with 95% confidence interval achieved by bootstrapping. *Continuous variable, analyzed by Pearson's correlation. ^ Kappa statistic: non-ranked non-parametric data analyzed by kappa statistics. N total; total number with both PSID and reference examinations in the analyses, N pathology; total number with the described pathology.

Table 5. Sensitivity, specificity, positive and negative predictive value of POCKET to detect pathology compared to reference method.

To detect	Operator	$N_{pathology}$ (N_{total})	Sensitivity	Specificity	PPV	NPV
At least moderate LV dysfunction	*Cardiologists*	35 (108)	97 %	99 %	97 %	99 %
	Medical residents	30 (129)	92 %	94 %	80 %	98 %
Any LV regional dysfunction	*Cardiologists*	35 (108)	97 %	99 %	92 %	96 %
Any RV dysfunction	*Cardiologists*	10 (106)	90 %	99 %	82 %	98 %
	Medical residents	10 (115)	40 %	97 %	57 %	94 %
Any dilatation of the left atrium	*Cardiologists*	69 (107)	81 %	68 %	85 %	73 %
	Medical residents	68 (117)	62 %	94 %	93 %	64 %
Any abdominal aortic aneurysms	*Cardiologists*	7 (67)	100 %	100 %	100 %	100 %
Any pleural effusion[1]	*Cardiologists*	14 (85)	93 %	98 %	87 %	97 %
Any pericardial effusion	*Cardiologists*	9 (108)	89 %	99 %	100 %	100 %
At least moderate aortic stenosis	*Cardiologists*	8 (106)	63 %	100 %	100 %	97 %
	Medical residents	37 (119)	76 %	88 %	74 %	89 %
At least moderate aortic regurgitation	*Cardiologists*	6 (106)	83 %	99 %	83 %	99 %
	Medical residents	27 (117)	82 %	89 %	69 %	94 %
At least moderate mitral regurgitation	*Cardiologists*	14 (107)	93 %	99 %	93 %	99 %
	Medical residents	48 (123)	71 %	81 %	71 %	81 %
At least moderate tricuspid regurgitation	*Cardiologists*	8 (108)	88 %	98 %	78 %	98 %
	Medical residents	49 (107)	65 %	90 %	85 %	75 %

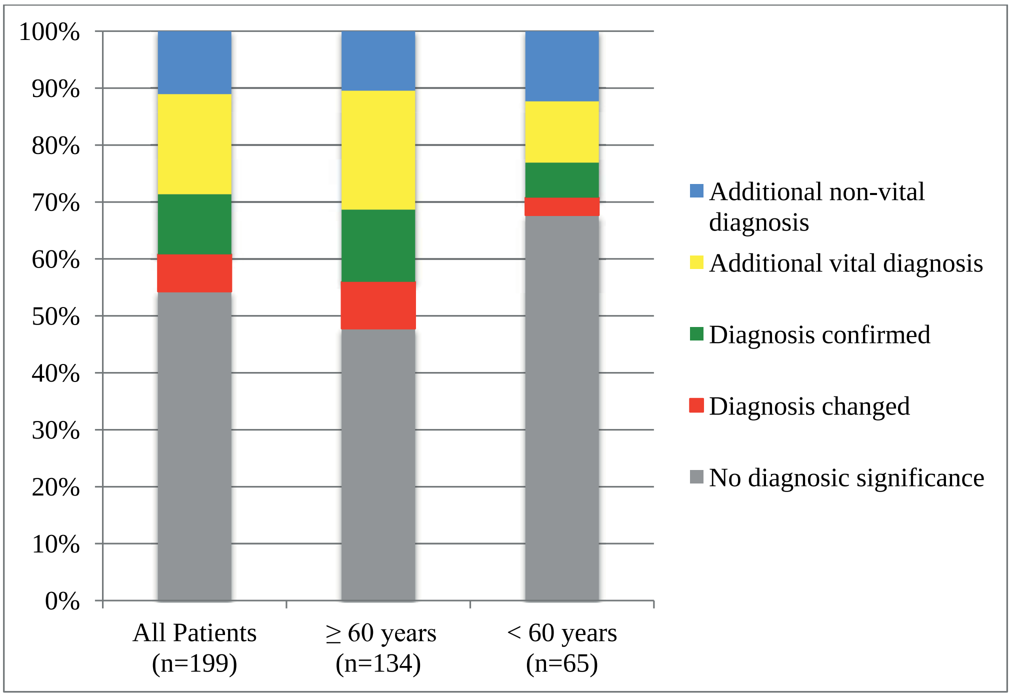
Abbreviations: N_{total}, total number in the analyses; $N_{pathology}$, total number with the described pathology. [1]Reference method was radiologic examinations and high-end echocardiography. In case of doubt, radiologic examination was used.

Study 3: The medical residents each performed a median of 27 (19-46) pocket-size ultrasound examinations. In 69 (35%) patients, pocket-size ultrasound examination was found to be of diagnostic influence as it changed, verified or added an additional important diagnosis (Table 6 and Figure 5). Pocket-size ultrasound examination resulted in a major change of the primary diagnosis in 13 (6.5%) patients. The diagnosis was verified in 21 (10.5%) patients and in 48 (24%) patients an additional important diagnosis was made. An additional non-clinically important diagnosis (defined as a new diagnosis not influencing treatment or generating further follow-up) was made in a further 25 (13%) patients.

In several patients the diagnostic yield was seen in more than one category i.e. in nearly 1/2 of the patients where the diagnosis was verified, an additional clinically important diagnosis was made. Similarly in 1/3 of patients whom had their diagnosis changed, an additional clinically important diagnosis was made. Out of six residents, four changed the primary diagnosis at least once (median 1.5 (range 0-7)) after pocket-size ultrasound examination and all residents showed diagnostic influence with the use of pocket-size ultrasound (median 10 (range 6-27)).

Age and the presence of increased cardiovascular risk differed significantly between those with change of the primary diagnosis and as those with any diagnostic influence of pocket-size ultrasound compared to those without (Figure 4). Mean age was 10 years higher in the group where pocket-size ultrasound examination changed or influenced the diagnosis ($p \leq 0.02$) compared to those without change or influence to their diagnosis. Increasing age and presence of cardiovascular risk predicted the influence of pocket-size ultrasound examinations with 39% and 82% higher risk of changing the diagnosis per 10 year of age and presence of cardiovascular risk factors, respectively. However when age was adjusted for cardiovascular risk and the presence of cardiovascular risk factors was adjusted for age, only age remained as a significant predictor of diagnostic influence.

Figure 5. Diagnostic influence of pocket-size ultrasound medical residents



Diagnostic usefulness of routinely adding a cardiovascular and abdominal examination with pocket-size ultrasound in all patients and specifically in those over and under 60 years of age. Reproduced from Paper 3 with permission from the American Institute of Ultrasound in Medicine.

Table 6 Diagnostic influence of goal-directed point-of-care cardiovascular and abdominal examination with pocket-size ultrasound performed by cardiologists and medical residents.

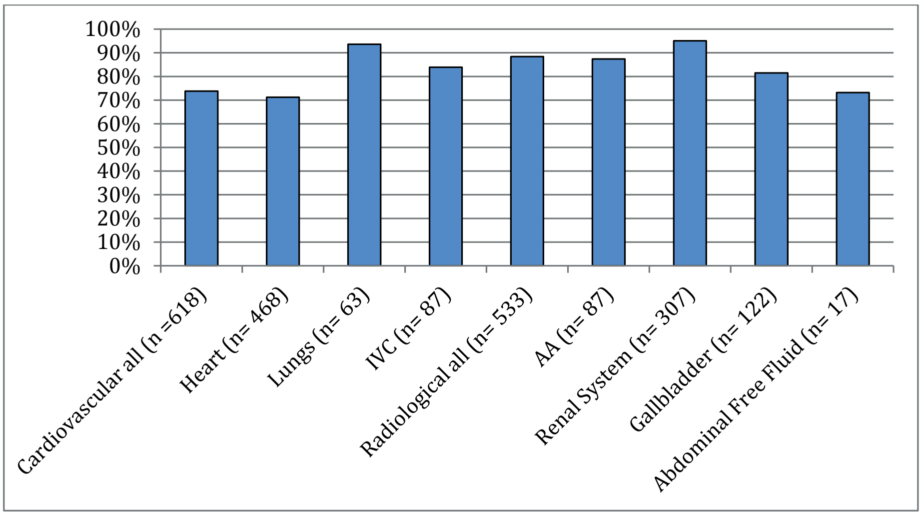
	Cardiologist	**Medical Residents**
	% (Number)	**% (Number)**
Change of primary diagnosis	18.4% (36)	6.5% (13)
Verification of primary diagnosis	19.4% (38)	10.5% (21)
Important additional diagnosis *	9.2% (18)	24% (48)
Non-important additional diagnosis**	N.A.	12.5% (25)
No diagnostic use	53.1 % (104)	54% (108)

N.A.; not applicable
* Important additional diagnosis; a diagnosis influencing treatment or follow-up. E.g.; heart failure, hypertrophic obstructive cardiomyopathy, regional wall motion abnormalities, significant valvular pathology, dilated ascending aorta, ascites, pericardial and pleural effusions, urinary retention, hypovolemia and fluid overload
**Non-important additional diagnosis; a diagnosis not influencing treatment or follow-up, E.g.; insignificant valvular pathology, gallstones and simple renal cysts.

Study 4: Acceptable organ presentation (Figure 6) was estimated to 74% (95% CI 63-83) for cardiovascular (heart, lungs and IVC) and 88% (95% CI: 81-94) for radiological (AA, renal system, gallbladder and abdominal free fluid) structures. Specifically, students performed best when acquiring images of the lungs and renal system (>93% (95% CI: 84-98). The students found it most difficult to acquire acceptable images of the heart (71% (95% CI: 59-82)) and abdominal free fluid (73% (95% CI: 41-92)). The other categories (AA, IVC and gallbladder) had acceptable presentation in >80% (95% CI: 65-99) of the cases. Diagnostic accuracy (Figure 7) was estimated at 93% (95% CI: 89-96) for cardiovascular structures and

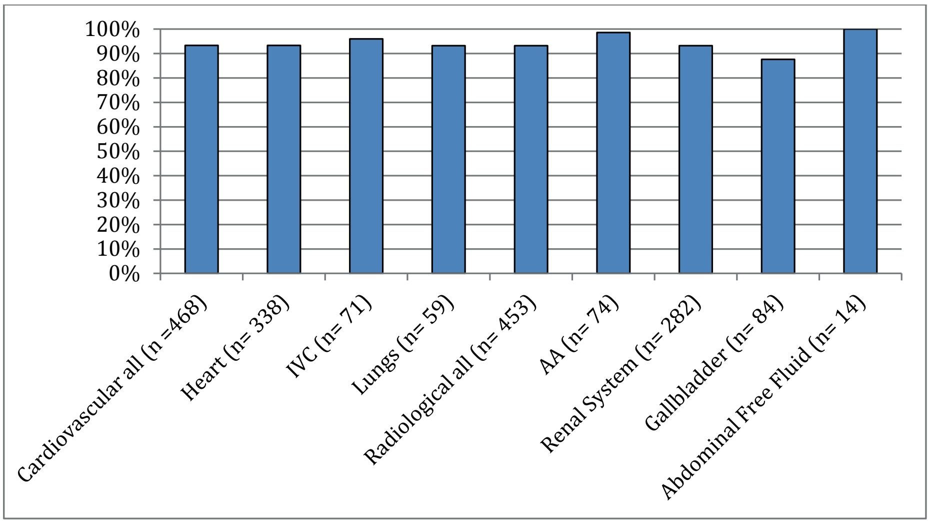
93% (95% CI: 87-97) for radiological structures. On the whole, diagnostic accuracy was excellent with measures for AA 99% (95% CI: 93-100) and free abdominal fluid 100% (95% CI: 77-100). The accuracy was lowest for classification of pathology in the gallbladder, 88% (95% CI: 74-95). The remaining categories showed diagnostic accuracy of >93% (95% CI: 83-99). The estimated values for sensitivity, specificity, negative and positive predictive values of PSID are presented in Table 8.

Figure 6. Acceptable Organ Presentation Students



Cardiovascular all; heart, IVC and Lungs, IVC; Inferior vena cava, Radiological all; includes AA, Renal system, Gallbladder and Abdominal free fluid. AA; Abdominal aorta. Reproduced from paper 4 with permission from BioMed Central Ltd.

Figure 7. Correct Diagnosis Students



Cardiovascular all; heart, IVC and Lungs, IVC; Inferior vena cava, Radiological all; includes AA, Renal system, Gallbladder and Abdominal free fluid. AA; Abdominal aorta. Reproduced from paper 4 with permission from BioMed Central Ltd.

Table 8 medical students. Sensitivity, specificity, positive and negative predictive values.

Pathology to detect	N Pathology (N total)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)
All cardiovascular	156 (468)	95.5 (90.9-97.9)	92.4 (83.7-96.9)	87.0 (75.3-93.4)	97.6 (95.0-98.8)
Cardiac only	115 (338)	98.3 (93.9-100)*	90.8 (78.8-96.7)	84.5 (62.6-95.6)	99.0 (96.4-99.9) *
IVC	20 (71)	84.5 (57.2-96.3)	100 (93.0-100) *	100 (80.5-100)*	94.8 (82.9-98.7)
Lungs	21 (59)	90.5 (68.8-97.6)	94.7 (82.2-99.4)*	90.5 (69.6-98.6) *	94.7(82.2-99.2)*
All abdominal	104 (453)	92.6 (83-97.1)	92.2 (82.9-96.9)	80.1 (63.3-91.0)	97.5 (92.6-99.2)
AA	12 (74)	91.7 (61.5-98.6)*	100 (94.2-100)*	100 (71.3-100)*	98.4 (91.5-99.6)*
Renal System	48 (282)	89.9 (77.2-95.9)	93.3 (82.5-98.0)	73.1 (48.4-89.6)	97.5 (85.7-99.7)
Gallbladder	35 (84)	94.3 (80.8-99.1)*	85.6 (71.5-93.4)	82.4 (63.7-93.1)	95.5 (84.5-99.3*
Abdominal free fluid	9 (14)	100 (66.2-100)*	100 (48.0-100)*	100 (66.2-100)*	100 (48.0-100)*

N; number, CI; confidence interval, PPV positive predictive value, NPV; negative predictive value, IVC; inferior vena cava, AA; abdominal Aorta. * Clopper-Pearson CI. Reproduced from paper 4 with permission from BioMed Central Ltd.

6. Discussion

6.1 Clinical examination

The accuracy of the physical examination when performed by experts can be remarkable (44-46). Certainly in the past when clinicians dealt with patients whom presented with advanced and untreated pathological processes and had little or no imaging tests available, the value of the history and physical examination was unmatched. However, physical examination has its limitations. There are several conditions such as, LV dysfunction, pericardial effusion, AAA and aortic insufficiency, for which traditional physical examination will always remain under par compared with echocardiography and ultrasonography (47-51).

As our pathophysiological knowledge has increased so has our diagnostic arsenal. We are able to diagnose illness earlier. This has been further fuelled by the increasing amounts of available treatments for the condition. The advances in modern medicine have increased the complexity of the playing field and led to an increased utilization of expensive and time consuming diagnostics at the cost of simple and time honed skills in physical examination (52, 53).

In today's medicine we are able to identify the exact genetic structure of cancer cells with the aid of advanced and expensive tests resulting in the optimal treatment and survival of the patient (54). Nevertheless, we are less accurate than previous generations in the art of physical examination and in particular the accuracy of the cardiac exam has suffered (6-8). The consequences of this cannot simply be ignored. For example, accurate clinical evaluation of the jugular venous pressure at the patients' bedside has valuable diagnostic and prognostic implication (55, 56). Unfortunately the ability to do so is often poor, especially for physicians in training (57, 58).

The decline of these relatively simple skills from modern medicine may have fatal consequences (59, 60). In fact, autopsy studies continue to show diagnostic errors in up to 30% of patients, despite the apparent availability of modern medical diagnostics.(61-63). This rate has remained largely unchanged, except for in patients suffering from cardiovascular disease. In this patient group the decline in diagnostic errors has paralleled the increased use of the echocardiographic examinations (64).

Modern diagnostics may not be available in every setting for several reasons, including overuse, cost, logistics and technical reasons. In these settings we must again rely on our clinical expertise. Furthermore, it is our skill in history taking and physical examination that will ultimately guide us to the next step of investigation or treatment. Thus, there is a strong rational for combining traditional clinical examination with point-of-care ultrasonography to augment the feasibility, reliability and accuracy of physical examination.

6.2 Training and education

"Medicine is learned by the bedside and not in the classroom…" -Sir William Osler.

Traditionally, highly trained individuals with a high degree of clinical expertise have performed ultrasonography and echocardiography in dedicated, dark rooms using large and cumbersome high-end scanners with a complex range of diagnostic functions. The mastering of this art takes a significant amount of time and resources.

Recent technological advances have resulted in pocket-size ultrasound. Although portable and convenient, they lack some of the diagnostic utilities of the high-end scanners. With bedside examination the need for dedicated rooms and patient transport is removed, but the decreased functionality of pocket-size ultrasound also negatively influences the scope of the clinical questions that can be answered. Thus, the degree of training and expertise required to successfully use pocket-size ultrasound at the patients point-of-care will differ from that required to perform formal echocardiography, additionally, it will differ with the clinical setting and which questions the examiner will try to answer.

In line with the recommendations from the EACVI the cardiologists participating in study 1 received no further training. Whilst the medical residents and students using pocket-size ultrasound in Studies 2, 3 and 4 each received education and training in its use, tailored to specific objectives (36, 38). The training was mixture of didactic education and hands-on training with simultaneous image interpretation. The medical residents had a much more comprehensive training program reflecting the fact that they were expected to perform more complicated assessments than the medical students. All the studies were carried out prior to the release of the EACVI Education Programme for Pocket-Size Ultrasound Devices (39).

Point-of-care ultrasonography is already being used by different specialties, from nurses and GPs to intensivists, in metropolitan hospital settings, 3rd world, rural and remote medicine and war zones (65-69). The spectrum of diseases and clinical scenarios differ between different specialties and locations and some associations have even begun to publish their own guidelines for its use (70). Non-experts must be taught, not only to obtain the relevant information by pocket-size ultrasound, but also how to use the collected data. For the benefit of the patients, good training and education is mandatory and essential to fully implement this technology in a safe and reliable manner.

6.3 Feasibility, reliability and accuracy

Studies 1 and 2 were studies on feasibility and reliability performed in a comparable manner with semi-quantitative assessments by experts and medical residents respectively. Pocket-size ultrasound examinations were performed at the bedside, under suboptimal conditions, on emergency admissions without any exclusion criteria. We found high feasibility and strong correlations for cardiac structures and function when performed by experts and somewhat lower feasibility and correlation when performed by medical residents. As 2D ejection fraction (EF) measurements show poor results for inter- and intra-user variability, LV function was assessed by semi-quantitative visual assessment or “eyeballing” method (71-74). This semi-quantitative approach showed an almost perfect correlation with the reference method in the hands of experts and non-experts, and in our opinion reflects the manner in which pocket-size ultrasound will be most useful in the assessment of LV function. Most of the other studies on the feasibility and reliability of pocket-size ultrasound have been performed under optimal conditions in the echocardiography lab. Prinz and Voigt published the first study assessing the feasibility and accuracy of the Vscan® in 2010. It was performed on 349 consecutive routine patients referred for formal echocardiography. All examinations were performed by experienced echocardiographers in the echocardiography lab directly prior to or after the high-end examination, which was performed by a separate examiner and both were blinded to the results of the other. They showed both excellent feasibility and reliability for the assessment of LV ejection fraction, LA size, detection of valvular disease and pericardial effusions ($r \leq 0.91$, $p \leq 0.01$).

A second study by Prinz et al with 320 patients showed moderate to almost perfect correlations between pocket-size ultrasound and formal echocardiography for the assessment of cardiac and valvular function, as well as chamber size, when recorded by cardiac sonographers and interpreted by experienced echocardiographers (75). Lafitte et al later published work on 100 patients referred for echocardiography comparing Vscan® and high-end machines in a semi-quantitative manner in the hands of experts; i.e. LV function was classified as normal, moderate or severe dysfunction. They also showed good to excellent concordance for most indices including image quality (76). One of the first studies looking at the use of Vscan® in the hands of experts and non-experts in a clinical scenario was the Naples Ultrasound Stethoscope in Cardiology (NaUSiCa) study published by Galderisi et al (77). This was another relatively large study with 304 outpatients referred from the department of endocrinology and oncology to a cardiac clinic. Patients were assessed by experts (102 patients) and non-experts (202 patients) by physical examination, pocket-size ultrasound and then formal high-end echocardiography specifically assessing for; LV ejection fraction, wall thickness, RV dilation, certain valvular diseases, pericardial and pleural effusions, and IVC size and respiratory variation. Exclusion criteria included poor image quality, clinically overt heart failure, history of coronary heart disease, or primary cardiomyopathies. They found good to very good agreement for most indices, with better results for the expert echocardiographers.

In studies 1 and 2 we found poorest feasibility for the abdominal great vessels with only 77% feasibility, but perfect correlation ($r = 1.0$) when performed by experts and 50% feasibility and slight to moderate correlation ($r = 0.5$) when performed by medical residents.

The feasibility is somewhat lower than that seen in Dijos et al in a study specifically assessing the abdominal aorta with a Vscan® in the hands of experts (78). They found similar correlation (*r* = 0.98) to Study 1, but a higher feasibility (97.5%). This may be explained by several factors. Firstly, the sole purpose of the pocket-size exam was to study the AA. Patients were a mix of inpatients and elective outpatients. Although most exams were performed at the bedside, it is not clear as to what clinical state the patients were in i.e. fasting/non-fasting, nor whether or not they were acute emergency admissions. The patients in Study 1 and 2 were all non-fasting emergency admissions, often in acute or semi acute distress. Furthermore, the reported time for screening for AAA with the Vscan® was 4 minutes. In studies 1 and 2 the total median time for a complete cardiovascular exam, including an assessment of the AA was 4.2 and 5.7 min, respectively. Thus, it is clear that significantly more time and effort was put into the evaluation of the AA by Dijos et al, which may in part explain the higher feasibility.

IVC measurements showed only moderate correlation, which is most likely due to the time delay between pocket-size and high-end ultrasound examination. The dimension of the IVC is an indirect measurement of right atrial filling pressure and the median delay between the pocket-size and high-end examinations of 17-20 hours probably biased the results, relating to any given treatment, physiologic and pathological conditions (79, 80). This is further confirmed by a recent study by Dalen et al showing excellent agreement between Vscan® in the hands of nurses and reference imaging for assessing the IVC. In this study the time delay between the examinations was minimal (65).

The estimation of LA size showed substantial correlation in studies 1 and 2 with *r* = 0.61 and 0.65 respectively. The correlation is somewhat lower than in comparative studies already outlined above (75, 76) and may relate to the lack of ECG timing and M-mode combined with real life bedside examination conditions.

The absence of spectral Doppler makes the assessment of valvular pathology according to recommended guidelines problematic (81-83). Instead the quantification of pathology was assessed based on colour Doppler, grey scale images of leaflet thickening, calcification and mobility, as well as, the influence on the adjacent chambers. Despite this the previously mentioned studies tend to show good correlation in the hands of experts, but with a tendency to overestimate regurgitant lesions and underestimate stenotic lesions (25).

There are several other pocket-size imaging devices on the market (24), but the two most studied are the Vscan® from GE Healthcare and the Acuson P10® from Siemens. There are no head-to-head comparison studies of the different pocket-size ultrasound machines. They compare similarly in many regards, but the Vscan® has the advantage of having a colour Doppler function. The previously discussed studies have all been using the Vscan®. However, there are several studies showing high feasibility and correlation between the Acuson P10® and a high-end scanner in the hands of experts under optimal conditions to assess cardiac chambers and function (26, 84). Two smaller studies by Culp et al using the Acuson P10® for estimation of LV ejection fraction shows moderate to substantial correlation and substantial to almost perfect correlation in the hands of novice and experienced echocardiographers, respectively, when performed on both intubated and awake patients (85, 86).

Up until very recently studies on the feasibility and accuracy of pocket-size ultrasound in the hands of medical students have been lacking. Cawthorn et al included 12 first year and 45 third year medical students in a study. They looked at different educational programs and compared them to the results obtained by each student whilst performing a focused cardiac ultrasound examination with a Vscan®. The 3rd year medical students performed well regardless of the educational program used, being able to acquire acceptable images on a healthy male volunteer and interpret a set of images provided by the study coordinators correctly >67% of the time. The first year students were less successful with only modest results (87).

As expected, the acquiring of acceptable cardiac recordings was the most challenging for the medical students in Study 4. In expectancy of this we attempted to minimize the impact of poor image quality and inexperience by teaching the students to measure MAE from an apical four-chamber view as a surrogate for LV function (41-43, 88). This may have contributed to the high accuracy in interpreting images from heart seen in Study 4.

6.4 Clinical benefit of point-of-care pocket-size examination

As outlined above, pocket-size ultrasound provides users with good quality images allowing them to make an accurate diagnosis, but the clinical benefit of this has yet to be elaborated.

In Study 3 medical residents examined 199 emergency admissions to the medical department and found a clinical diagnostic influence of adding a pocket-size ultrasound examination to standard care in >1/3 of patients. Two other studies by our research group were performed in similar scenarios, but this time the Vscan® was used in the hands of experts looking at newly admitted general medicine and cardiology patients. They showed a diagnostic influence (i.e. changed, verified or added an additional important diagnosis) in approximately 50% of patients (89, 90). The difference in diagnostic influence is most likely related to the experience of the operators, and supports the hypothesis that the gain of adding the pocket-size ultrasound screening is largest among the most experienced users (24). In studies 1 and 2 we found high sensitivity and specificity for most indices, with more impressive results seen when the pocket-size ultrasound examinations were performed by experts. In the previously described NaUSiCa study, Galderisi et al showed a high level of accuracy with overall sensitivity and specificity being 91% and 76%. Not surprisingly the addition of pocket-size ultrasound examination to the physical examination resulted in an increased diagnostic accuracy for the above mentioned cardiac abnormalities from 38% to 70%. Many of these abnormalities such as LV hypertrophy and systolic dysfunction may be difficult to detect reliably without imaging tests (77).

A more recent study by Panoulas et al, which included five final year medical students and three junior doctors, found promising results by adding a pocket-size ultrasound examination to standard history, physical examination and ECG in 122 cardiology patients. Specifically, the addition of an ultrasound examination (Vscan®) after history taking, physical examination and ECG increased the diagnostic accuracy from 49% to 75%. It also increased the sensitivity and specificity of detecting LV systolic dysfunction from 25% and 85% to 74% and 94% respectively (91).

The cost effectiveness of implementing pocket-size ultrasound examination into clinical practice has been reported in two separate studies. In a study by Cardim et al pocket-size ultrasound examination was used as an adjunct to the physical examination by cardiologists. They showed a 60% reduction in unnecessary echocardiography referrals and an increase in adequate referrals by nearly 30%; in total they found that referrals for echocardiography dropped form 50.3% to 33.9%. In addition they were able to discharge nearly 20% of the patients from further follow-up (92). Kitada et al have recently published data from a cost-effective analysis were they show expected cost reductions of 10-40%, depending on the strategy used, across hospitals in the USA, Asia and Europe by implementing the routine use of pocket-size ultrasound in clinical practice to select those whom would benefit the most from formal high-end echocardiography(84).

The high sensitivity, specificity, positive and negative predictive values of pocket-size ultrasonography with respect to detect at least moderate pathology shows that it may serve as an efficient and cost-effective tool for triage of the patient in need of further advanced imaging (92). However, although point-of-care pocket-size ultrasonography can quickly provide a limited semi-quantitative assessment, it is not as accurate or reliable as the gold standard techniques. Thus, pocket-sized ultrasonography should be used as an adjunct to the physical examination, as a tool for quick screening and to identify patients in need of advanced imaging modalities. In settings where referral to formal imaging modalities is actually warranted, pocket-size imaging is no substitute.

7. Limitations

Studies 1, 2 and 3 were all single centre studies with a limited number of participating doctors and patients. Whilst Study 4 was conducted at several different locations, there were a limited number of medical students and patients.

In all Studies, pocket-size ultrasound examination was performed at the bedside, under sub-optimal conditions. Thereby, the pocket-size ultrasound and the formal, high-end examinations were performed under different conditions, which may have influenced both the feasibility and reliability. However, the aim of these studies was to assess the feasibility, reliability and diagnostic influence of pocket-size ultrasound examination at the bedside in real life scenarios. The radiologists performing the control exams in Study 2 were unfortunately not blinded to the results of the pocket-size ultrasound examination due to in-hospital logistics. This may have biased some of the results.

Out of the 446 patients eligible to receive pocket-size ultrasound examinations in Studies 2 and 3, only 199 were actually examined. This somewhat low proportion is chiefly explained by busy working hours, in-hospital logistics and the residents being instructed to prioritize standard diagnostics. Although patients allocated to undergo pocket-size ultrasound examinations were not necessarily examined consecutively, selection bias has seemingly been minimal with the exception of patients with known malignancy who were significantly overrepresented in the control groups. Such patients are more likely to be admitted for palliation purposes, which may explain the finding.

Studies 2 and 3 were a single centre study with a limited number of participating residents and patients. Due to internal logistics half of the 12 residents were randomized by draw to perform the pocket-size ultrasound examinations, instead of the more optimal randomisation of patients. Analyses in Study 3 were performed as treated and not as intent-to-treat.

Selection bias was also a concern in Study 4. The medical students selected their own patients and were also able to select which ultrasound images/loops were eligible for review. This may have led to some overestimation of the feasibility and accuracy results, but the degree of selection bias is in line with similar studies involving unselected medical residents and nurses (93, 94). Of the 30 students included nine were excluded; one student did not hand-in a logbook, although he performed more than 200 examinations, and a further eight did not perform any examinations with their pocket-size ultrasound device. There are probably several reasons for the students not performing examinations. Firstly, the use of pocket-size ultrasound in their clinical placement was not a part of their curriculum. Secondly as this was a trial the students were instructed not to let it come in the way of their other academic responsibilities. Finally, patient inclusion into the study was performed by the medical students themselves, which may have created a further barrier for its use. Finally, all ultrasonography is operator dependant, whereby enthusiastic students will likely acquire more images with better quality. Thus, reflecting a more realistic picture of its clinical use, with those skilled in ultrasonography also being the ones using it the most and with most gain.

8. Pocket-size ultrasound in the future

The addition and incorporation of routine point-of-care pocket-size ultrasound as an adjunct to the standard physical examination will likely continue to spread throughout modern medicine in the years to come. It has been shown to safely and rapidly increase the accuracy of physical examination.

The use of pocket-size ultrasound will probably not, nor should it for the time being, replace standard high-end diagnostics, due to its lack of certain key functions such as spectral Doppler, linear probes and limited user interface. However, we can expect the areas of use to expand, as suppliers improve the software and hardware of these devices.

We may expect further miniaturization and increased functionality of hardware from several vendors such as interchangeable or combined probes to assist in vascular and intraarticular access, diagnosis of pneumothorax, deep vein thrombosis and arthritis. The recently launched “Vscan with dual probe” is equipped with a probe combining the qualities of the linear and cardiac sector probes.

Today specific software is used for external data storage. Better software is needed to simplify data transfer and storage and to incorporate findings more easily into hospital picture archiving and communication systems (PACS) and records in a similar manner to ECGs and chest x-rays. This will lower the threshold for using the pocket-size ultrasound even further. It will also facilitate in the future diagnosis of patients in situations where an old ultrasound recording is easily accessible to the next clinician encountering the patient. Additionally the ability to safely transfer an image loop to an external expert for review and guidance at the patients’ point-of-care may prove valuable as the use of pocket-size ultrasound expands.

Another avenue for future progress lies in the fields of automation of measurements, such as automatic MAE and EF measurements (95). This will aid inexperienced operators, as well as help standardize measurements such as the 2D EF, which is prone to a significant amount of inter- and intra-observer variability, even in experienced hands (71-73).

The dispersion of point-of-care pocket size ultrasound to different specialties with users of various levels of experience has begun. The next logical step, which is already transpiring, is the incorporation of pocket-size ultrasound into the curriculum of medical schools on the same line as stethoscopy (9696). In the not so distant future we can probably expect the use of point-of-care ultrasound to be as common and synonymous with certain parts of the medical profession as the stethoscope.

9. Conclusions

Pocket-size ultrasound can be implemented safely, at the bedside, as an adjunct to physical examination in the routine clinical practice of both experienced and in-experienced operators. Bringing the diagnosis back to the bedside has the ability to effectively improve patient care and diagnostics at a low cost.

Experts and medical residents were able to use pocket-size ultrasound to produce high-quality semi-quantitative assessment of cardiac structures and function, abdominal great vessels and the pleural space at the bedside in real-life clinical practice in approximately 4 and 6 minutes, respectively. Furthermore, medical residents with limited training in ultrasonography were able to quickly change or verify the primary diagnosis and/or reveal an additional diagnosis important for treatment or follow-up in one of three (35%) patients by adding point-of-care pocket-size ultrasound examinations to standard care.

Medical students with minimal training were able to use pocket-size ultrasound as a supplement to their standard physical examination and successfully acquire acceptable relevant organ images for presentation and correctly interpret these with great accuracy.

In summary, pocket-size ultrasound examination performed by experts, medical residents and even medical students is feasible, reliable and accurate. As ultrasound examinations are user dependant, better results are seen when performed by the more experienced and dedicated users. To maximize the potential benefit of pocket-size ultrasonography, education should start at an early stage in the physicians' career and be viewed as a skill of equal value to that of traditional stethoscopy.

"The trouble with doctors is not that they don't know enough, but that they don't see enough."

—Sir Dominic J. Corrigan (1802-1880)

References:

1. Walker HK. The Origins of the History and Physical Examination. In: Walker HK HW, Hurst JW, editors. Clinical Methods: The History, Physical, and Laboratory Examinations. 3rd edition. Boston: Butterworths; 1990. Chapter 1. Available from: http://www.ncbi.nlm.nih.gov/books/NBK458/.
2. Roelandt JR. Ultrasound stethoscopy: a renaissance of the physical examination? Heart. 2003 Sep;89(9):971-3.
3. Kremer W. An electronic revolution in the doctor's bag. BBC World Service. 2014.
4. Roelandt JR. The decline of our physical examination skills: is echocardiography to blame? Eur Heart J Cardiovasc Imaging. 2013 Nov 25.
5. Mangione S, Nieman LZ. Cardiac auscultatory skills of internal medicine and family practice trainees: A comparison of diagnostic proficiency. JAMA. 1997;278(9):717-22.
6. Mangione S. Cardiac auscultatory skills of physicians-in-training: a comparison of three English-speaking countries. Am J Med. 2001 Feb 15;110(3):210-6.
7. Vukanovic-Criley JM, Criley S, Warde CM, Boker JR, Guevara-Matheus L, Churchill WH, et al. Competency in cardiac examination skills in medical students, trainees, physicians, and faculty: a multicenter study. Arch Intern Med. 2006 Mar 27;166(6):610-6.
8. Johnson JE, Carpenter JL. Medical house staff performance in physical examination. Arch Intern Med. 1986 May;146(5):937-41.
9. Wray NP, Friedland JA. Detection and correction of house staff error in physical diagnosis. JAMA. 1983;249(8):1035-7.

10. Fred HL. Hyposkillia: deficiency of clinical skills. Tex Heart Inst J. 2005;32(3):255-7.

11. Edler I, Hertz CH. The use of ultrasonic reflectoscope for the continuous recording of the movements of heart walls. 1954. Clin Physiol Funct Imaging. 2004 May;24(3):118-36.

12. Griffith JM, Henry WL. A sector scanner for real time two-dimensional echocardiography. Circulation. 1974 Jun;49(6):1147-52.

13. Somer JC. Electronic sector scanning for ultrasonic diagnosis. Ultrasonics. 1968 Jul;6(3):153-9.

14. Wells PN. A range-gated ultrasonic Doppler system. Med Biol Eng. 1969 Nov;7(6):641-52.

15. Kasai C, Namekawa K, Koyano A, Omoto R. Real- time two-dimensional blood flow imaging using an auto-correlation technique. IEEE Trans Sonics Ultrason 1985;32:460–3.

16. Brubakk AO, Angelsen BA, Hatle L. Diagnosis of valvular heart disease using transcutaneous Doppler ultrasound. Cardiovasc Res. 1977 Sep;11(5):461-9.

17. Hatle L, Angelsen B, Tromsdal A. Noninvasive assessment of atrioventricular pressure half-time by Doppler ultrasound. Circulation. 1979 Nov;60(5):1096-104.

18. Hatle L, Angelsen BA, Tromsdal A. Non-invasive assessment of aortic stenosis by Doppler ultrasound. Br Heart J. 1980 Mar;43(3):284-92.

19. Hatle L, Angelsen BA, Tromsdal A. Non-invasive estimation of pulmonary artery systolic pressure with Doppler ultrasound. Br Heart J. 1981 Feb;45(2):157-65.

20. Hatle L, Brubakk A, Tromsdal A, Angelsen B. Noninvasive assessment of pressure drop in mitral stenosis by Doppler ultrasound. Br Heart J. 1978 Feb;40(2):131-40.

21. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al. Recommendations for chamber quantification. Eur J Echocardiogr. 2006 Mar;7(2):79-108.

22. Moore GE. Cramming More Components onto Integrated Circuits Electronics. 1965 Aptil 19:114-7.

23. Bom N, van der Steen AF, de Jong N, Roelandt JR. Early, recent and future applications of echocardiography. Clin Physiol Funct Imaging. 2004 May;24(3):141-6.

24. Dalen H, Haugen BO, Graven T. Feasibility and clinical implementation of hand-held echocardiography. Expert Rev Cardiovasc Ther. 2013;11(1):49-54.

25. Prinz C, Voigt J-U. Diagnostic Accuracy of a Hand-Held Ultrasound Scanner in Routine Patients Referred for Echocardiography. J Am Soc Echocardiogr. 2011;24(2):111-6.

26. Fukuda S, Shimada K, Kawasaki T, Fujimoto H, Maeda K, Inanami H, et al. Pocket-sized transthoracic echocardiography device for the measurement of cardiac chamber size and function. Circ J. 2009 Jun;73(6):1092-6.

27. Moore CL, Copel JA. Point-of-Care Ultrasonography. N Engl J Med. 2011;364(8):749-57.

28. Roelandt JR. The 50th anniversary of echocardiography: are we at the dawn of a new era? Eur J Echocardiogr. 2003 Dec;4(4):233-6.

29. Miller AH, Roth BA, Mills TJ, Woody JR, Longmoor CE, Foster B. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. Acad Emerg Med. 2002 Aug;9(8):800-5.

30. Jakobsen CJ, Torp P, Sloth E. Perioperative feasibility of imaging the heart and pleura in patients with aortic stenosis undergoing aortic valve replacement. Eur J Anaesthesiol. 2007 Jul;24(7):589-95.

31. Scalea TM, Rodriguez A, Chiu WC, Brenneman FD, Fallon WF, Jr., Kato K, et al. Focused Assessment with Sonography for Trauma (FAST): results from an international consensus conference. J Trauma. 1999 Mar;46(3):466-72.

32. Moore CL, Holliday RS, Hwang JQ, Osborne MR. Screening for abdominal aortic aneurysm in asymptomatic at-risk patients using emergency ultrasound. Am J Emerg Med. 2008 Oct;26(8):883-7.

33. Lemola K, Yamada E, Jagasia D, Kerber RE. A hand-carried personal ultrasound device for rapid evaluation of left ventricular function: use after limited echo training. Echocardiography. 2003 May;20(4):309-12.

34. Mouratev G, Howe D, Hoppmann R, Poston MB, Reid R, Varnadoe J, et al. Teaching medical students ultrasound to measure liver size: comparison with experienced clinicians using physical examination alone. Teach Learn Med. 2013 Jan;25(1):84-8.

35. Wittich CM, Montgomery SC, Neben MA, Palmer BA, Callahan MJ, Seward JB, et al. Teaching cardiovascular anatomy to medical students by using a handheld ultrasound device. JAMA. 2002 Sep 4;288(9):1062-3.

36. Sicari R, Galderisi M, Voigt JU, Habib G, Zamorano JL, Lancellotti P, et al. The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. Eur J Echocardiogr. 2011 Feb;12(2):85-7.

37. Spencer KT, Kimura BJ, Korcarz CE, Pellikka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr. 2013 Jun;26(6):567-81.

38. Neskovic AN, Edvardsen T, Galderisi M, Garbi M, Gullace G, Jurcut R, et al. Focus cardiac ultrasound: the European Association of Cardiovascular Imaging viewpoint. Eur Heart J Cardiovasc Imaging. 2014 Sep;15(9):956-60.

39. EACVI Education Programme for Pocket Size Devices. Available from: http://learn.escardio.org/eacvi-pocket-size-programme.

40. Vignon P, Chastagner C, Berkane V, Chardac E, François B, Normand S, et al. Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. Crit Care Med. 2005;33(8):1757-63.

41. Alam M, Hoglund C, Thorstrand C. Longitudinal systolic shortening of the left ventricle: an echocardiographic study in subjects with and without preserved global function. Clin Physiol. 1992 Jul;12(4):443-52.

42. Hoglund C, Alam M, Thorstrand C. Atrioventricular valve plane displacement in healthy persons. An echocardiographic study. Acta Med Scand. 1988;224(6):557-62.

43. Alam M, Hoglund C, Thorstrand C, Philip A. Atrioventricular plane displacement in severe congestive heart failure following dilated cardiomyopathy or myocardial infarction. J Intern Med. 1990 Dec;228(6):569-75.

44. Pestana C, Weidman WH, Swan HJ, McGoon DC. Accuracy of preoperative diagnosis in congenital heart disease. Am Heart J. 1966 Oct;72(4):446-50.

45. Lembo NJ, Dell'Italia LJ, Crawford MH, O'Rourke RA. Bedside diagnosis of systolic murmurs. N Engl J Med. 1988 Jun 16;318(24):1572-8.

46. Roldan CA, Shively BK, Crawford MH. Value of the cardiovascular physical examination for detecting valvular heart disease in asymptomatic subjects. Am J Cardiol. 1996 Jun 15;77(15):1327-31.

47. Berger M, Bobak L, Jelveh M, Goldberg E. Pericardial effusion diagnosed by echocardiography. Clinical and electrocardiographic findings in 171 patients. Chest. 1978 Aug;74(2):174-9.

48. Grayburn PA, Smith MD, Handshoe R, Friedman BJ, DeMaria AN. Detection of Aortic Insufficiency by Standard Echocardiography, Pulsed Doppler Echocardiography, and AuscultationA Comparison of Accuracies. Ann Intern Med. 1986;104(5):599-605.

49. Riba AL, Morganroth J. Unsuspected substantial pericardial effusions detected by echocardiography. JAMA. 1976 Dec 6;236(23):2623-5.

50. Lederle FA, Walker JM, Reinke DB. Selective screening for abdominal aortic aneurysms with physical examination and ultrasound. Arch Intern Med. 1988 Aug;148(8):1753-6.

51. Rovai D, Morales MA, Di Bella G, Prediletto R, De Nes M, Pingitore A, et al. Echocardiography and the clinical diagnosis of left ventricular dysfunction. Acta Cardiol. 2008 Aug;63(4):507-13.

52. Schattner A. Clinical paradigms revisited. Med J Aust. 2006 Sep 4;185(5):273-5.

53. Sackett DL, Rennie D. The science of the art of the clinical examination. JAMA. 1992 May 20;267(19):2650-2.

54. Rosell R, Moran T, Queralt C, Porta R, Cardenal F, Camps C, et al. Screening for epidermal growth factor receptor mutations in lung cancer. N Engl J Med. 2009 Sep 3;361(10):958-67.

55. Drazner MH, Rame JE, Stevenson LW, Dries DL. Prognostic importance of elevated jugular venous pressure and a third heart sound in patients with heart failure. N Engl J Med. 2001 Aug 23;345(8):574-81.

56. Dao Q, Krishnaswamy P, Kazanegra R, Harrison A, Amirnovin R, Lenert L, et al. Utility of B-type natriuretic peptide in the diagnosis of congestive heart failure in an urgent-care setting. J Am Coll Cardiol. 2001 Feb;37(2):379-85.

57. Brennan JM, Blair JE, Goonewardena S, Ronan A, Shah D, Vasaiwala S, et al. A Comparison by Medicine Residents of Physical Examination Versus Hand-Carried

Ultrasound for Estimation of Right Atrial Pressure. The American Journal of Cardiology. 2007 6/1/;99(11):1614-6.

58. McGee SR. Physical examination of venous pressure: a critical review. Am Heart J. 1998 Jul;136(1):10-8.

59. Maisel AS, Peacock WF, McMullin N, Jessie R, Fonarow GC, Wynne J, et al. Timing of immunoreactive B-type natriuretic peptide levels and treatment delay in acute decompensated heart failure: an ADHERE (Acute Decompensated Heart Failure National Registry) analysis. J Am Coll Cardiol. 2008 Aug 12;52(7):534-40.

60. Wuerz RC, Meador SA. Effects of prehospital medications on mortality and length of stay in congestive heart failure. Ann Emerg Med. 1992 Jun;21(6):669-74.

61. Combes A, Mokhtari M, Couvelard A, Trouillet JL, Baudot J, Henin D, et al. Clinical and autopsy diagnoses in the intensive care unit: a prospective study. Arch Intern Med. 2004 Feb 23;164(4):389-92.

62. Kirch W, Schafii C. Misdiagnosis at a university hospital in 4 medical eras. Medicine (Baltimore). 1996 Jan;75(1):29-40.

63. Pastores SM, Dulu A, Voigt L, Raoof N, Alicea M, Halpern NA. Premortem clinical diagnoses and postmortem autopsy findings: discrepancies in critically ill cancer patients. Crit Care. 2007;11(2):R48.

64. Sonderegger-Iseli K, Burger S, Muntwyler J, Salomon F. Diagnostic errors in three medical eras: a necropsy study. Lancet. 2000 Jun 10;355(9220):2027-31.

65. Dalen H, Gundersen GH, Skjetne K, Haug HH, Kleinau JO, Norekval TM, et al. Feasibility and reliability of pocket-size ultrasound examinations of the pleural cavities and vena cava inferior performed by nurses in an outpatient heart failure clinic. Eur J Cardiovasc Nurs. 2014 Aug 13.

66. Mjølstad OC, Snare SR, Folkvord L, Helland F, Grimsmo A, Torp H, et al. Assessment of left ventricular function by GPs using pocket-sized ultrasound. Fam Pract. 2012 October 1, 2012;29(5):534-40.

67. Vignon P, Dugard A, Abraham J, Belcour D, Gondran G, Pepino F, et al. Focused training for goal-oriented hand-held echocardiography performed by noncardiologist residents in the intensive care unit. Intensive Care Med. 2007 Oct;33(10):1795-9.

68. Beaton A, Aliku T, Okello E, Lubega S, McCarter R, Lwabi P, et al. The utility of handheld echocardiography for early diagnosis of rheumatic heart disease. J Am Soc Echocardiogr. 2014 Jan;27(1):42-9.

69. Nations JA, Browning RF. Battlefield applications for handheld ultrasound. Ultrasound quarterly. 2011 Sep;27(3):171-6.

70. Emergency ultrasound guidelines. Ann Emerg Med. 2009 Apr;53(4):550-70.

71. Hoffmann R, von Bardeleben S, ten Cate F, Borges AC, Kasprzak J, Firschke C, et al. Assessment of systolic left ventricular function: a multi-centre comparison of cineventriculography, cardiac magnetic resonance imaging, unenhanced and contrast-enhanced echocardiography. Eur Heart J. 2005 Mar;26(6):607-16.

72. Otterstad JE. Measuring left ventricular volume and ejection fraction with the biplane Simpson's method. Heart. 2002 Dec;88(6):559-60.

73. Jenkins C, Bricknell K, Chan J, Hanekom L, Marwick TH. Comparison of two- and three-dimensional echocardiography with sequential magnetic resonance imaging for evaluating left ventricular volume and ejection fraction over time in patients with healed myocardial infarction. Am J Cardiol. 2007 Feb 1;99(3):300-6.

74. Shahgaldi K, Gudmundsson P, Manouras A, Brodin LA, Winter R. Visually estimated ejection fraction by two dimensional and triplane echocardiography is closely

correlated with quantitative ejection fraction by real-time three dimensional echocardiography. Cardiovasc Ultrasound. 2009;7:41.

75. Prinz C, Dohrmann J, van Buuren F, Bitter T, Bogunovic N, Horstkotte D, et al. The importance of training in echocardiography: a validation study using pocket echocardiography. J Cardiovasc Med (Hagerstown). 2012 Nov;13(11):700-7.

76. Lafitte S, Alimazighi N, Reant P, Dijos M, Zaroui A, Mignot A, et al. Validation of the smallest pocket echoscopic device's diagnostic capabilities in heart investigation. Ultrasound Med Biol. 2011 May;37(5):798-804.

77. Galderisi M, Santoro A, Versiero M, Lomoriello VS, Esposito R, Raia R, et al. Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples Ultrasound Stethoscope in Cardiology) study. Cardiovasc Ultrasound. 2010;8:51.

78. Dijos M, Pucheux Y, Lafitte M, Reant P, Prevot A, Mignot A, et al. Fast track echo of abdominal aortic aneurysm using a real pocket-ultrasound device at bedside. Echocardiography. 2012 Mar;29(3):285-90.

79. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. Am J Cardiol. 1990 Aug 15;66(4):493-6.

80. Tchernodrinski S, Lucas BP, Athavale A, Candotti C, Margeta B, Katz A, et al. Inferior vena cava diameter change after intravenous furosemide in patients diagnosed with acute decompensated heart failure. J Clin Ultrasound. 2014 Jun 4.

81. Baumgartner H, Hung J, Bermejo J, Chambers JB, Evangelista A, Griffin BP, et al. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. Eur J Echocardiogr. 2009 Jan;10(1):1-25.

82. Lancellotti P, Tribouilloy C, Hagendorff A, Moura L, Popescu BA, Agricola E, et al. European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 1: aortic and pulmonary regurgitation (native valve disease). Eur J Echocardiogr. 2010 Apr;11(3):223-44.

83. Lancellotti P, Moura L, Pierard LA, Agricola E, Popescu BA, Tribouilloy C, et al. European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease). Eur J Echocardiogr. 2010 May;11(4):307-32.

84. Kitada R, Fukuda S, Watanabe H, Oe H, Abe Y, Yoshiyama M, et al. Diagnostic accuracy and cost-effectiveness of a pocket-sized transthoracic echocardiographic imaging device. Clin Cardiol. 2013 Oct;36(10):603-10.

85. Culp BC, Mock JD, Chiles CD, Culp WC, Jr. The pocket echocardiograph: validation and feasibility. Echocardiography. 2010 Aug;27(7):759-64.

86. Culp BC, Mock JD, Ball TR, Chiles CD, Culp WC, Jr. The pocket echocardiograph: a pilot study of its validation and feasibility in intubated patients. Echocardiography. 2011 Apr;28(4):371-7.

87. Cawthorn TR, Nickel C, O'Reilly M, Kafka H, Tam JW, Jackson LC, et al. Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students. J Am Soc Echocardiogr. 2014 Mar;27(3):302-9.

88. Yuda S, Inaba Y, Fujii S, Kokubu N, Yoshioka T, Sakurai S, et al. Assessment of left ventricular ejection fraction using long-axis systolic function is independent of image quality: a study of tissue Doppler imaging and m-mode echocardiography. Echocardiography. 2006 Nov;23(10):846-52.

89. Mjølstad OC, Dalen H, Graven T, Kleinau JO, Salvesen O, Haugen BO. Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department. Eur J Intern Med. 2012;23(2):185-91.

90. Skjetne K, Graven T, Haugen BO, Salvesen Ø, Kleinau JO, Dalen H. Diagnostic influence of cardiovascular screening by pocket-size ultrasound in a cardiac unit. Eur J Echocardiogr. 2011 October 1, 2011;12(10):737-43.

91. Panoulas VF, Daigeler AL, Malaweera AS, Lota AS, Baskaran D, Rahman S, et al. Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. Eur Heart J Cardiovasc Imaging. 2013 Apr;14(4):323-30.

92. Cardim N, Fernandez Golfin C, Ferreira D, Aubele A, Toste J, Cobos MA, et al. Usefulness of a New Miniaturized Echocardiographic System in Outpatient Cardiology Consultations as an Extension of Physical Examination. J Am Soc Echocardiogr. 2011;24(2):117-24.

93. Ruddox V, Stokke TM, Edvardsen T, Hjelmesaeth J, Aune E, Baekkevar M, et al. The diagnostic accuracy of pocket-size cardiac ultrasound performed by unselected residents with minimal training. Int J Cardiovasc Imaging. 2013 Dec;29(8):1749-57.

94. Henderson SO, Ahern T, Williams D, Mailhot T, Mandavia D. Emergency department ultrasound by nurse practitioners. J Am Acad Nurse Pract. 2010 Jul;22(7):352-5.

95. Snare SR, Mjolstad OC, Orderud F, Haugen BO, Torp H. Fast automatic measurement of mitral annulus excursion using a pocket-sized ultrasound system. Ultrasound Med Biol. 2011 Apr;37(4):617-31.

96. Solomon SD, Saldana F. Point-of-care ultrasound in medical education--stop listening and look. N Engl J Med. 2014 Mar 20;370(12):1083-5.

Paper 1

European Journal of Echocardiography (2011) **12**, 665–670
doi:10.1093/ejechocard/jer108

Feasibility and reliability of point-of-care pocket-sized echocardiography

Garrett Newton Andersen[1,2*], Bjørn Olav Haugen[2,3], Torbjørn Graven[1], Øyvind Salvesen[4], Ole Christian Mjølstad[2,3], and Håvard Dalen[1,2]

[1]Levanger Hospital, Nord-Trøndelag Health Trust, Levanger, Norway; [2]MI Laboratory, Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Box 8905, 7491 Trondheim, Norway; [3]Department of Cardiology, St Olavs Hospital/Trondheim University Hospital, Trondheim, Norway; and [4]Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, Trondheim, Norway

Received 3 May 2011; accepted after revision 22 June 2011; online publish-ahead-of-print 2 August 2011

Aims To study the reliability and feasibility of point-of-care pocket-sized echocardiography (POCKET) at the bedside in patients admitted to a medical department at a non-university hospital.

Methods and results One hundred and eight patients were randomized to bedside POCKET examination shortly after admission and later high-end echocardiography (HIGH) in the echo-lab. The POCKET examinations were done by cardiologists on their ward rounds. Assessments of global and regional left ventricular (LV) function, right ventricular (RV) function, valvular function, left atrial (LA) size, the pericardium and pleura were done with respect to effusion and measurements of inferior vena cava (IVC) and abdominal aorta (AA) were performed. Correlations between POCKET and HIGH/appropriate radiological technique for LV function, AA size and presence of pericardial effusion were almost perfect, with $r \geq 0.92$. Strong correlation ($r \geq 0.81$) was shown for RV and valvular function, except for grading of aortic stenosis ($r = 0.62$). The correlations were substantial for IVC and LA dimensions. Median time used for bedside screening with POCKET was 4.2 min (range: 2.3–13.0). There was excellent feasibility for cardiac structures and pleura, which was assessed to satisfaction in ≥94% of patients. Lower feasibility (71–79%) was seen for the abdominal great vessels.

Conclusion Point-of-care semi-quantitative evaluation of cardiac anatomy and function showed high feasibility and correlation with the reference method for most indices. Pocket-sized echocardiographic examinations of ∼4 min length, performed at the bedside by experts, offers reliable assessment of cardiac structures, the pleural space and the large abdominal vessels.

Clinical trial registration: http://www.clinicaltrials.gov; unique ID: NCT01081210.

Keywords Echocardiography • Pocket-size • Hand-held • Screening • Point-of-care ultrasound • Bedside

Introduction

With limited resources and an increasing need for speed in the health-care system, the advent of cheaper and more user friendly miniaturized ultrasound scanners is appealing. Pocket-sized scanners can now easily be brought to the patient, so-called point-of-care ultrasonography.[1] The recently published recommendations for the use of pocket-sized echocardiography (POCKET) by the European Association of Echocardiography states that POCKET may serve as a tool for fast initial screening and as complement to the physical examination.[2] Further, POCKET may be used for the triage of the patient in need of a complete echocardiographic examination and has the potential to rearrange inpatient workflow and diagnostics.[2–5]

Recent studies have shown good correlation between POCKET and high-end echocardiography (HIGH) in both outpatient cardiac

* Corresponding author. Tel: +47 48 22 25 66; fax: +47 72 82 83 72. Email: garrett.andersen@gmail.com

clinics and echo-labs,[4,6–8] which offer optimal conditions for echocardiography. Even though the pocket-sized ultrasound devices are designed for point-of-care ultrasonography, it is not known whether bedside examinations with inferior conditions for echocardiography are feasible and reliable. Thus, we aimed to study the feasibility and reliability of POCKET as a bedside cardiovascular screening tool and adjunct to the physical examination in routine clinical ward rounds in patients admitted to a medical department.

Methods

Study population

One hundred and ninety-six patients admitted to the medical department at Levanger Hospital, Norway between March and September 2010 were scanned with POCKET (Vscan; GE Vingmed, Horten, Norway) by one of the three experienced cardiologists on their regular on-call ward rounds. Selection was random, based solely on admission dates.

The specialist on call for general medicine at this hospital is either 1 of 3 cardiologists experienced in echocardiography or one of the 10 other specialists in internal medicine. Patients were only available for inclusion if one of the three cardiologists were on call the day the patients were admitted to hospital.

Patients admitted to the departments' cardiac unit (119 patients) were automatically referred to a subsequent HIGH examination. In addition, all patients from the non-cardiac units with standard indications for echocardiography were also referred and included in the analyses. Exclusion criteria included death or discharge before completed study protocol or withdrawal of consent. Patients were specifically not excluded due to poor image quality, previous illness or any other unspecified attribute. In total, 90 patients from the cardiac unit and 18 patients from the non-cardiac units underwent both POCKET and HIGH and these 108 patients are included in the analyses.

Written informed consent was obtained. The study was approved by the Regional Committee for Medical and Health Research Ethics and conducted according to the Declaration of Helsinki.

Pocket-sized echocardiographic screening

The ultrasound screening was performed at the bedside with a pocket-sized ultrasound device, Vscan (GE Vingmed Ultrasound, Horten, Norway). The device weighs 390 g, including the phased-arrayed probe, which measures 135 × 73 × 28 mm. The device offers two-dimensional grey scale and live colour Doppler imaging. The image sector for echocardiographic imaging is 75°. The bandwidth ranges from 1.7 to 3.8 MHz and is automatically adjusted. An algorithm enables automatic storage and looping of a cardiac cycle without ECG signal.[9] The length of recordings of other structures is predefined and limited to 2 s. Patient identification was performed by voice recording and the automatically assigned examination number. All images and recordings were saved on the device's micro-SD card and later transferred to a computer by commercial software (Gateway; GE Vingmed Ultrasound).

A standardized screening protocol was used. The cardiovascular screening by POCKET was performed at the bedside with patients in a left-lateral decubitus and supine position. Assessment of left ventricular (LV) global and regional function, right ventricular (RV) size and function, valvular anatomy and function, and the pericardium were done from parasternal long- and short-axis and apical four-chamber, two-chamber and long-axis views. Global LV and RV functions were classified online by visual assessment as: normal/near normal, moderate dysfunctional or severe dysfunctional, while regional LV function was classified as regional dysfunction present or not. Valvular pathology and dysfunction were classified as mild, moderate or severe by visual assessment from grey-scale and colour Doppler imaging. The area and intensity of the regurgitation jets assessed by colour Doppler were the most important for grading valvular regurgitations, while the grading of aortic stenosis was based on the degree of calcification and the movement of the cusps. Pericardial effusion was classified as present or not. The size of the left atrium was measured online on grey-scale parasternal long-axis images. An attempt was made in order to do the measurement at end systole. From the subxiphoid position, the abdominal aorta (AA) and inferior vena cava were assessed by grey-scale imaging. The AA was assessed distally to the bifurcation and classified as: no abdominal aortic aneurysm present or abdominal aortic aneurysm present, depending on whether the diameter exceeded 35 mm or not. In case of doubt by visual assessment, measurement was done by the device's calliper mode. The inferior vena cava diameter was measured end-expiratory within 2 cm from the right atrium orifice. All measurements of size were done on the POCKET. With patients in a supine position, the pleura was assessed by grey-scale imaging from left and right lateral views, and the amount of pleural effusion was classified as: no pleural effusion, small-to-moderate amounts of pleural effusion or significant pleural effusion.[10] All recordings were saved on the POCKET and the time used for the screening was calculated as the time from start to end of the examination.

Validation of point-of-care pocket-sized echocardiography

HIGH was performed in the hospital's echo-lab, under optimal conditions, with a Vivid 7 scanner (GE Vingmed Ultrasound, Horten, Norway) using a 2.0-MHz phased-array transducer (M3S) with bandwidth 1.5–3.6 MHz. The scanner weighs 190 kg. Second harmonic imaging was used and the sector angle set to 90° as default, but was adjusted when appropriate. Storage and looping of cardiac cycles were ECG triggered. HIGH examinations were performed independently by one of four experienced cardiologists blinded to the results of POCKET with a median time delay of 17.3 h. The same cardiovascular structures as described above were measured and classified according to the guidelines of the European Association of Echocardiography (EAE).[11–15] Ejection fraction was measured by Simpson's rule from apical four-chamber and two-chamber views. Dimensions were measured by M-mode from parasternal recordings.[14] Valvular pathology was graded according to the recommendations from the EAE.[11–13] Additionally, imaging techniques such as computer tomography, magnetic resonance imaging or ultrasound were ordered according to standard care and performed at the Department of Radiology. For the analyses in the patients who underwent both echocardiographic and radiologic examinations, the radiologists' grading of pleural effusion and size of the AA was preferred compared with the echocardiography.

In a randomized subset of 20 study participants, the high-end echocardiographic recordings were reanalysed by a second cardiologist blinded to the original measurements in order to test inter-analyser variability.

Statistics

The basic characteristics are presented as mean ± standard deviation (SD) and range. The Spearman's rho (r) was used for comparison of the grading of pathology between the POCKET and the HIGH or radiologic examinations. Data are presented as r [95% confidence interval (CI)] with CI computed using bootstrapping. For comparison of continuous variables between the POCKET and the HIGH examinations, Pearson's rho (r) was used. The reliability of HIGH is expressed by the coefficient of variation and was calculated as the within subjects SD of the two sets of observations, divided by the mean of the observations. A two-tailed $P < 0.05$ was considered significant. All statistical analyses were performed using SPSS for Windows (version 18.0, SPSS Inc., Chicago, IL, USA).

Results

Study population

Basic characteristics of the study population are shown in *Table 1*. Age was mean ± SD (range) 69.1 ± 13.7 (20–92) years and 36% were female. Mean BMI was 27 ± 5 (17–44) kg/m^2 and LV ejection fraction was 60 ± 15 (19–86)%, respectively.

Pocket-sized echocardiography

Median time used for POCKET was 4.2 min (range: 2.3–13.0). Image quality and interpretation were generally good (*Table 2*). Specifically a high feasibility (≥98%) for cardiac structures was seen, whilst it was somewhat lower for non-cardiac structures such as the intra-abdominal vessels (≥71%).

The correlations of semi-quantitative assessment of cardiovascular structures and function indices between POCKET and HIGH are shown in *Tables 3* and *4*. LV regional and global function and RV size and function showed almost perfect correlation with r (95% CI): 0.92 (0.83–0.99), 0.95 (0.90–0.99) and 0.85 (0.65–1.0), respectively. Classification of valvular function indices between POCKET and HIGH correlated well for aortic, mitral and tricuspid regurgitations ($r \geq 0.81$). Grading of aortic valve calcification or stenosis showed substantial correlation with r (95% CI): 0.62 (0.42–0.79). *Table 4* and *Figure 1* illustrate the agreement of POCKET with HIGH regarding the assessments of valvular function. Severe pulmonary regurgitation and mitral stenosis was only present in one patient each and no pulmonary stenosis was detected (data not tabulated).

Visual estimation of the size of the AA had perfect correlation (1.0) with respect to detecting aneurysms ≥35 mm. Seven (10%) patients had abdominal aortic aneurysms. The degree of LA dilatation and end-expiratory IVC diameter showed a less robust correlation, both $r = 0.65$ (IVC, $r^2 = 0.42$). Pericardial effusion was detected in nine (8%) patients and in one patient with insignificant pericardial effusion this was missed by POCKET. Detection of pleural effusions had an overall correlation of $r = 0.82$ (0.79–1.0). In total 14 patients had pleural effusion detected by HIGH. No

Table 1 Basic characteristics of the 108 study participants

Variable	Mean ± SD (range)[a]
Age, years	69.1 ± 13.7 (20–92)
Women, *n* (%)	39 (36%)
Height (cm)	172 ± 9 (146–189)
Body mass index (kg/m^2)	27 ± 5 (17–44)
Systolic blood pressure (mm Hg)	146 ± 32 (58–250)
Diastolic blood pressure (mm Hg)	81.5 ± 20 (32–161)
Heart rate (bpm)	78.7 ± 24 (29–145)
Atrial fibrillation, *n* (%)	22 (20%)
Prior hypertension, *n* (%)	39 (36%)
Prior diabetes, *n* (%)	18 (17%)
Prior myocardial infarction, *n* (%)	33 (31%)
Prior angina, *n* (%)	27 (25%)
Prior heart failure, *n* (%)	12 (11%)
Prior peripheral vessel disease, *n* (%)	13 (12%)
Prior stroke, *n* (%)	12 (11%)

[a]Data are presented as mean ± SD (range) unless otherwise specified.

Table 2 Feasibility of point-of-care pocket-sized echocardiography

Structure	Assessed to satisfaction, *n* (%)
Left ventricle	108 (100)
Right ventricle	106 (98)
Pericardial space	108 (100)
Left atrium	105 (97)
Heart valves[a]	≥106 (98)
Pleural space	102 (94)
AA	77 (71)
Inferior vena cava	85 (79)

[a]Aortic, mitral, tricuspid and the pulmonary valves.

Table 3 Correlations of semi-quantitative echocardiographic indices between pocket-sized echocardiography and reference method

Grading of:	n_{total}	$n_{pathology}$	r (95% CI)
Global LV function	108	35	0.95 (0.90–0.99)
Apparent LV regional dysfunction	108	35	0.92 (0.83–0.98)
RV function	106	10	0.85 (0.65–1.0)
Size of the left atrium[a]	107	69	0.65 (0.51–0.76)
AA[a]	67	7	1.0 (1.0)
Pleural effusion[a]	85	14	0.89 (0.74–1.0)
Inferior vena cava[b]	76	—	0.68 (0.53–0.80)
Pericardial effusion	108	9	0.94 (0.78–1.0)
Aortic calcification and stenosis	106	24	0.62 (0.42–0.79)
Aortic regurgitation	106	31	0.92 (0.83–0.98)
Mitral regurgitation	107	54	0.89 (0.82–0.95)
Tricuspid regurgitation	108	34	0.81 (0.69–0.91)

n_{total}, total number in the analyses; $n_{pathology}$, total number with the described pathology. [a]Reference method was radiologic examinations and high-end echocardiography. In case of doubt, radiologic examination was used.
[b]Pearsons' correlation, all other analysed by Spearman's rank correlation.

Table 4 Agreement between point-of-care pocket-sized echocardiography and reference echocardiography of different cardiac indices

Indices (n = total/ pathology)	All examinations, POCKET −2/−1/ 0/+1/+2 grades misclassification	Examinations in diseased, POCKET −2/−1/0/+1/+2 grades misclassification
Global LV function (n = 107/35)	—/4/98/5/—	—/4/27/4/—
Regional LV function[a] (n = 106/35)	—/1/103/2/—	—/1/34/—/—
Global RV function (n = 107/10)	—/1/104/2/—	—/1/9/—/—
LA size (n = 106/69)	—/20/73/12/1	—/20/46/3/—
Aortic stenosis (n = 106/24)	1/10/89/6/—	1/10/13/—/—
Aortic regurgitation (n = 106/31)	—/4/100/2/—	—/4/26/1/—
Mitral regurgitation (n = 107/54)	—/3/97/7/—	—/3/50/1/—
Tricuspid regurgitation (n = 108/34)	—/10/94/3/1	—/10/22/1/1

LV, left ventricle; RV, right ventricle; LA, left atrium.
POCKET −2/−1/0/+1/+2 refer to underestimation (−) and overestimation (+) by POCKET of the described indices compared with reference echocardiography.
[a]LV regional dysfunction was classified as present or not, i.e. only two categories.

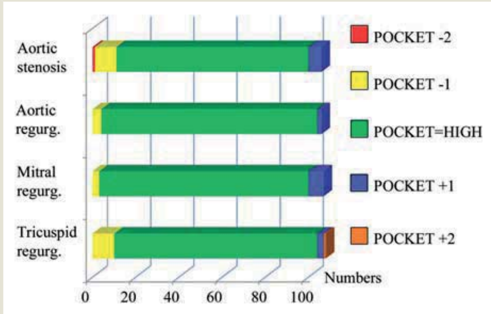


Figure 1 Agreement of grading valvular function with pocket-sized echocardiography compared with reference. All indices of valvular function graded as normal, or mild, moderate, and severe pathology. The number of patients with any; aortic valve calcification/stenosis, aortic regurgitation, mitral regurgitation, or tricuspid regurgitation by high-end echocardiography was 24, 31, 54, and 34, respectively. POCKET −2, −1, +1 and +2 refer to grades of underestimation (−) and overestimation (+) of the described pathology compared with reference echocardiography. Abbreviations: regurg, regurgitation.

significant amount of pleural effusion was missed. *Table 5* shows the high sensitivity, specificity, positive, and negative predictive values of POCKET with respect to detecting at least moderate pathology of the cardiovascular indices.

The coefficients of variation for all presented echocardiographic indices were ≤6.0%, indicating low interanalyser variability of the reference method. Mean ± SD (range) time used for reference echocardiography, excluding post-processing beyond calculation of ejection fraction was 17.2 ± 3.8 (12–32) min.

Discussion

This study of 108 patients admitted to a medical department shows that bedside, limited, semi-quantitative point-of-care ultrasound examination with a pocket-sized device can offer high-quality assessment of cardiac structures, cardiac function indices, abdominal great vessels and the pleural space. The pocket-sized ultrasound examinations were highly feasible and the agreement with reference methods was excellent for most indices.

The presented findings are in line with recent publications from echo lab's and outpatient clinics with respect to feasibility and reliability.[4,6–8] However, direct comparisons between studies are difficult due to different populations and exclusion criteria. We excluded only patients who did not consent to participate or remain long enough in-hospital to have a reference echocardiography for comparison.

Furthermore, our study was conducted at the bedside by cardiologists, in sub-optimal examination conditions, on call during busy working hours, in a department where most admissions are on an emergency basis.

As shown by Supplementary material online, *Figures S1 and S2* there was a modest underestimation of valvular pathology by POCKET compared with HIGH. This was most pronounced for classification of aortic stenosis. Visual detection of aortic stenosis by POCKET was inferior to high-end reference. This may be explained by the lack of spectral Doppler and the lower resolution (240 × 320 pixels) on the Vscan with inferior visualization of the valvular cusps. However, there was no misclassification of valvular dysfunction in those with severe aortic stenosis. Colour-coded images are limited by a low frame rate, but this is compensated for by the vendor by a high sensitivity. Very small or insignificant leakages may be bloomed and this may account for some of the overestimated pathology presented in Supplementary material online, *Figures S1 and S2*. There were no misclassifications of severe aortic, mitral and tricuspid regurgitations. Thus, it does not seem to be any limitation for the clinical use of the colour mode.

The size of the left atrium and the inferior vena cava showed only substantial agreement between POCKET and HIGH. This may primarily be related to timing of the measurements in the cardiac or respiratory cycles and the time delay of median 17 h between POCKET and HIGH. As the POCKET device is not able to show the cyclicity of the cardiac or respiratory phases, timing of measurements is done by visual assessment only. As

Table 5 **Sensitivity, specificity, positive, and negative predictive value of point-of-care pocket-sized echocardiography to detect pathology compared with reference method**

To detect:	$n_{pathology}$ (n_{total})	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
At least moderate LV dysfunction	35 (108)	97	99	97	99
Any LV regional dysfunction	35 (108)	97	99	92	96
Any RV dysfunction	10 (106)	90	99	82	98
Any dilatation of the left atrium	69 (107)	81	68	85	73
Any abdominal aortic aneurysms	7 (67)	100	100	100	100
Any pleural effusion[1]	14 (85)	93	98	87	97
Any pericardial effusion	9 (108)	89	99	100	100
At least moderate aortic stenosis	8 (106)	63	100	100	97
At least moderate aortic regurgitation	6 (106)	83	99	83	99
At least moderate mitral regurgitation	14 (107)	93	99	93	99
At least moderate tricuspid regurgitation	8 (108)	88	98	78	98

Abbreviations and explanations as in Table 3.

the dimension of the inferior vena cava is an indirect measure of right atrial filling pressure, the delay from POCKET to HIGH may bias the analyses of reliability, related both to physiologic conditions and any given treatment.[16] The lack of M-mode and ECG timing on the POCKET device may lead to inaccurate measurements.

The clinical implication of our study is that pocket-sized device can safely be implemented as a bedside screening device during ward rounds when operated by experienced users. Further work should address whether point-of-care POCKET influences workflow in hospitals and if our findings are reproducible by less-experienced users.

Limitations

The applicability of this study may be limited in that all POCKET examinations were performed by experienced cardiologists with a special interest in echocardiography. How feasible and reliable the use of POCKET by non-experts is in similar situations remains uncertain.

The POCKET examinations were performed under non-optimal conditions at the bedside. Thus, the POCKET and the HIGH examinations were performed under different conditions and this may influence both feasibility and reliability. However, the aim of this study was to assess the feasibility and reliability of POCKET used as a bedside screening device and therefore this was necessary.

The time delay (median 17.3 h) between POCKET and HIGH examinations may bias the analyses of reliability, related both to physiologic conditions, disease progression or regression and any given treatment.

Lack of spectral Doppler capability makes assessment of valvular pathology according to recommended guidelines difficult.[11–13] Instead the quantification of pathology was assessed based on colour Doppler, grey-scale images of leaflet thickening, calcification and mobility.

However, the high sensitivity, specificity, and positive and negative predictive values of POCKET with respect to detecting at least moderate pathology shows that POCKET may serve as an efficient tool for triage of the patient in need of a complete echocardiographic examination. Although POCKET quickly performs a limited semi-quantitative assessment well, it is not as accurate or reliable as the gold standard techniques. Pocket-sized echocardiography is as an adjunct to physical examination and a general screening tool. In settings where referral to formal imaging techniques is warranted POCKET is no substitute.

Conclusion

Focused point-of-care ultrasound examinations of 4 min duration with a pocket-sized device can offer high-quality semi-quantitative assessment of cardiac structures and function, as well as abdominal great vessels and the pleural space. The pocket-sized device can safely be implemented as a bedside screening device in the routine clinical practice of experienced operators.

Supplementary data

Supplementary data are available at *European Journal of Echocardiography* online.

Acknowledgements

G.N.A., B.O.H. and H.D. hold positions at MI Lab, a Centre of Research-based Innovation that is funded by the Research Council of Norway and industry. One of the industry partners is GE Vingmed Ultrasound. The Centre has a total budget of ~24 million NOK for the 8 years period from 2007 to 2014, and the contribution from GE Vingmed Ultrasound to this budget is ~7 million NOK (~6%).

Conflict of interest: none declared.

Funding

This study is funded by the Nord-Trøndelag Health Trust, Norway and the Norwegian University of Science and Technology, Norway.

References

1. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med* 2011;**364**: 749–57.
2. Sicari R, Galderisi M, Voigt J-U, Habib G, Zamorano JL, Lancellotti P *et al.* The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. *Eur J Echocardiogr* 2011;**12**:85–7.
3. Badano LP, Nucifora G, Stacul S, Gianfagna P, Pericoli M, Del Mestre L *et al.* Improved workflow, sonographer productivity, and cost-effectiveness of echocardiographic service for inpatients by using miniaturized systems. *Eur J Echocardiogr* 2009;**10**:537–42.
4. Cardim N, Fernandez Golfin C, Ferreira D, Aubele A, Toste J, Cobos MA *et al.* Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination. *J Am Soc Echocardiogr* 2011;**24**:117–24.
5. Kaul S, Miller JG, Grayburn PA, Hashimoto S, Hibberd M, Holland MR *et al.* A suggested roadmap for cardiovascular ultrasound research for the future. *J Am Soc Echocardiogr* 2011;**24**:455–64.
6. Culp BC, Mock JD, Chiles CD, Culp WC. The pocket echocardiograph: validation and feasibility. *Echocardiography* 2010;**27**:759–64.
7. Galderisi MSA, Versiero M, Lomoriello VS, Esposito R, Raia R, Farina F et al. Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples Ultrasound Stethoscope in Cardiology) study. *Cardiovasc Ultrasound* 2010;**8**:51.
8. Prinz C, Voigt J-U. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. *J Am Soc Echocardiogr* 2011;**24**: 111–6.
9. Aase SA, Snare SR, Dalen H, Støylen A, Orderud F, Torp H. Echocardiography without electrocardiogram. *Eur J Echocardiogr* 2011;**12**:3–10.
10. Vignon P, Chastagner C, Berkane V, Chardac E, François B, Normand S *et al.* Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. *Crit Care Med* 2005;**33**:1757–63.
11. Baumgartner H, Hung J, Bermejo J, Chambers J, Evangelista A, Griffin B *et al.* EAE/ASE. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. *Eur J Echocardiogr* 2009;**10**:1–25.
12. Lancellotti P, Moura L, Pierard LA, Agricola E, Popescu BA, Tribouilloy C *et al.* European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease). *Eur J Echocardiogr* 2010;**11**:307–32.
13. Lancellotti P, Tribouilloy C, Hagendorff A, Moura L, Popescu BA, Agricola E *et al.* European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 1: aortic and pulmonary regurgitation (native valve disease). *Eur J Echocardiogr* 2010;**11**:223–44.
14. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA *et al.* Recommendations for chamber quantification. *Eur J Echocardiogr* 2006;**7**: 79–108.
15. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA *et al.* Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr* 2009;**10**:165–93.
16. Kircher BJ, Himelman HR, Schiller NB. Non-invasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990;**66**:493–496.

Paper 2

European Heart Journal – Cardiovascular Imaging (2013) **14**, 1195–1202
doi:10.1093/ehjci/jet062

Feasibility and reliability of point-of-care pocket-size echocardiography performed by medical residents

Ole Christian Mjølstad[1,2]*, Garrett Newton Andersen[1,3], Håvard Dalen[1,3], Torbjørn Graven[3], Kyrre Skjetne[3], Jens Olaf Kleinau[3], and Bjørn Olav Haugen[1,2]

[1]MI Lab and Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Postboks 8905, Trondheim 7491, Norway; [2]Department of Cardiology, St Olav, Trondheim University Hospital, Prinsesse Kristinas gate 3, Trondheim 7006, Norway; and [3]Levanger Hospital, Nord-Trøndelag Health Trust, Levanger 7600, Norway

Received 5 February 2013; accepted after revision 26 March 2013; online publish-ahead-of-print 3 May 2013

Aims To study the feasibility and reliability of pocket-size hand-held echocardiography (PHHE) by medical residents with limited experience in ultrasound.

Methods and results A total of 199 patients admitted to a non-university medical department were examined with PHHE. Six out of 14 medical residents were randomized to use a focused protocol and examine the heart, pericardium, pleural space, and abdominal large vessels. Diagnostic corrections were made and findings were confirmed by standard diagnostics. The median time consumption for the examination was 5.7 min. Each resident performed a median of 27 examinations. The left ventricle was assessed to satisfaction in 97% and the pericardium in all patients. The aortic and atrioventricular valves were assessed in at least 76% and the abdominal aorta in 50%, respectively. Global left-ventricular function, pleural, and pericardial effusion showed very strong correlation with reference method (Spearman's $r \geq 0.8$). Quantification of aortic stenosis and regurgitation showed strong correlation with $r = 0.7$. Regurgitations in the atrioventricular valves showed moderate correlations, $r = 0.5$ and $r = 0.6$ for mitral and tricuspid regurgitation, respectively, similar to dilatation of the left atrium ($r = 0.6$) and detection of regional dysfunction ($r = 0.6$). Quantification of the abdominal aorta (aneurysmatic or not) showed strong correlation, $r = 0.7$, while the inferior vena cava diameter correlated moderately, $r = 0.5$.

Conclusion By adding a PHHE examination to standard care, medical residents were able to obtain reliable information of important cardiovascular structures in patients admitted to a medical department. Thus, focused examinations with PHHE performed by residents after a training period have the potential to improve in-hospital diagnostic procedures.

Keywords Echocardiography • Pocket-size • Hand-held • Point-of-care ultrasound • Bedside • Non-expert

Introduction

An early and correct diagnosis is a crucial step in the treatment of patients. A delayed or wrong diagnosis may delay the treatment, complicate inpatient workflow, and may in worst case scenario have a lethal outcome.[1]

During the recent two decades, the development of new digital technology and miniaturization of ultrasound scanners have moved these scanners from the echo-labs into the white coat pocket.[2,3] This makes them an excellent clinical tool, available for any physician in different clinical settings as a point-of-care ultrasonography.[4]

These newly developed scanners have been studied in several clinical settings. In the hands of experienced users, pocket-size hand-held echocardiographic (PHHE) devices offer high-quality semi-quantitative assessment of cardiac structures, abdominal great vessels, and the pleural space at the physicians' point-of-care with a demonstrable clinical benefit.[5–11]

* Corresponding author. Tel: + 47 970 34 285; Fax: + 47 72 82 83 72, Email: ole.c.mjolstad@ntnu.no

Medical history-taking and physical examination of most patients are performed by the residents in the emergency departments or bed wards. Few of these are skilled in ultrasonography and given the cost and the availability of the PHHE devices, non-expert users will frequently have such technology available for diagnostic use. Thus, we aimed to study the feasibility and reliability of PHHE in the hands of medical residents after a targeted training period in cardiovascular ultrasound.

Methods

Study population

This prospective observational study included 199 patients admitted to the medical department at Levanger Hospital, Norway. The patients were included in the period 4 April to 23 June 2011. The examination was performed by six medical residents taking part in the study. At study start, 12 medical residents were employed at the department, and half of them were randomized to participate in the study. During the study, another two residents joined the department, but they did not participate in the study. The residents have in-house call 24×7. Thus, the six participating residents covered ~42% of the total period of inclusion. All emergency admissions during the time these six residents were on call were included in the study. There were no other criteria of inclusion. Only patients who did not consent to participate or did not stay long enough in the department to enable the necessary diagnostic procedures for the study were excluded. Due to logistic reasons, inclusion of patients was restricted to 199 of 446 available patients as standard diagnostic procedures and treatment had first priority.

The patients were admitted to the emergency room in a standard way. After having been triaged according to their symptoms, they were examined by the resident. Based on the medical history, physical examination, and supplemental tests, a preliminary diagnosis was made. Thus, usual care diagnostics were done prior to the examination with PHHE. All patients had standard follow-up according to their symptoms and findings. Patients, in whom pathology was suggested either by PHHE or by the standard clinical care, were referred for relevant gold-standard diagnostic follow-up. To improve the reliability of the sensitivity and specificity of the data, approximately 10 negatively described PHHE examinations per resident were randomly selected by the study committee and referred for reference imaging procedures as well. The study was approved by the Regional Committee for Medical Research Ethics, and conducted according to the second Helsinki Declaration. All the patients gave their informed consent to participate in the study.

Education of residents

The residents underwent a brief training program covering both the examination with PHHE and interpretation of the recordings. The program consisted of 4 h of lectures dealing with the theoretical basics and pitfalls of cardiovascular ultrasonography. Normal and pathological findings were demonstrated, and they were all provided with access to a virtual ultrasound-imaging library. All participating residents had a personal supervisor. Subsequently, the residents underwent 3 months of practical training, initially together with the supervisors in the echo-lab and in the radiology department, then using PHHE in the medical department with close connection to experienced ultrasonographers, having the opportunity to discuss their findings. They were encouraged to perform at least 100 examinations during the tutorial period. The actual numbers performed were median (interquartile range) 95 (80–225) examinations.

Pocket-size echocardiographic examination

The residents performed the PHHE examinations using a Vscan (version 1.2; GE Vingmed Ultrasound, Horten, Norway). This device offers B-mode and colour flow (CF) imaging. The total weight is 390 g including the phased array probe with bandwidth of 1.7–3.8 MHz. It provides two dimensional (2D) imaging and real time colour-Doppler within a sector that has fixed size, but is movable throughout the 2D sector. An algorithm enables automatic storage and loop recording of a cardiac cycle without ECG signal.[12] Patient identification was performed by voice recording and the automatically assigned examination number. All images and recordings were saved on the device's micro-SD card and later transferred to a computer by commercial software (Gateway; GE Vingmed Ultrasound).

The pocket-size echocardiographic examinations were performed bedside, and when possible with the patients in the left-lateral decubitus position. The examinations included parasternal long- and short-axis views and apical four-chambers, two-chambers, and long-axis views. All views contained 2D and CF recordings. The patients were turned to supine position when examining the abdominal great vessels. The pleural space was recorded from supine or upright position. A standard examination protocol was used. Assessment of left- and right-ventricular function were done semi-quantitatively from the parasternal and apical positions, classified as normal/near normal, moderate, or severe dysfunction. The quantification was based on the systolic excursion of the atrioventricular plane for both ventricles. In addition, eye-balling of the left-ventricular ejection fraction as $\geq$45, 30–45, or $<$30% corresponded to normal/near normal, moderate, or severe dysfunction, respectively. With respect to the assessment of right-ventricular function, dilatation of the ventricle and/or diastolic shift to the left of the intraventricular septum was also included in the judgement. Severe regional dysfunction was classified as present or not. Valvular pathology and dysfunction was classified semi-quantitatively as mild, moderate, or severe. Quantification of stenosis was based on the amount of calcification and the movement of the cusps/leaflets. Quantification of the regurgitations was based on the CF jet and size and function of the adjacent chambers. The size of the left atrium (LA) was measured online from the parasternal position and quantified as normal ($<$40 mm), moderately dilated (40–50 mm), or severely dilated ($>$50 mm). Pericardial effusion was if present classified as significant or not based on visual judgement of the influence of the adjacent chambers. The inferior vena cava diameter was assessed from the subcostal position at the end expiration within 2 cm from the right atrial orifice. The size of the abdominal aorta was determined by the largest measured diameter. It was classified as aneurysmatic if the diameter exceeded 30 mm. Both pleural cavities were examined. If pleural effusion was present, this was graded as small or large amount. A large amount of pleural effusion was registered if the diameter between the thoracic wall and the lung exceeded 5 and 4.5 cm in the left or the right pleural cavity, respectively. The examinations of the different structures were judged by the residents as feasible if they were able to quantify the specific cardiac structures or function indices based on their recordings.

Validation of point-of-care pocket-size echocardiography

Standard echocardiography was performed in the hospital's echo-lab, under optimal conditions. The system used was a Vivid 7 scanner (GE Vingmed Ultrasound, Horten, Norway) using a 2.0 MHz phased-array transducer (M3S) with bandwidth 1.5–3.6 MHz. Second harmonic imaging was used. The recording of a cardiac cycle was ECG triggered. The standard examinations were performed independently by one of four experienced cardiologists blinded to the results of PHHE with a median (range) time delay of 21.1 (0.4–166) h. A complete echocardiographic examination was performed. Dimensions were measured from a parasternal view. Ejection fraction was measured by Simpson's rule from apical four- and two-chamber views.[13] Valvular pathology was graded according to the recommendations from the European Association of Cardiovascular Imaging (EACVI) [former European Association of Echocardiography (EAE)].[14–16] For the analyses of the patients who underwent both echocardiographic and radiographic examinations, the radiologists' classifications of pleural effusion [computer tomography (CT) or ultrasound] and the size of the abdominal aorta were preferred.

Statistical analysis

As the different echocardiographic and anthropometric measures partly were skewed compared with normal distribution, the basic characteristics are presented as mean ± standard deviation (SD) and (interquartile) range. Spearman's rho (*r*) was used for comparison of the ranking of pathology between the PHHE and the high-end echocardiographic examinations. Data are presented as *r* [95% confidence interval (CI)] with the 95% CI computed using bootstrapping. For comparison of continuous variables, Pearson's rho (*r*) and Bland–Altman statistics were used. Statistical analyses were performed using SPSS for Windows version 20.0 (SPSS, Inc., Chicago, IL, USA).

Results

Study population

Table 1 shows the baseline data of the 199 patients included in the study (107 men and 92 women). Mean ± SD (range) age was 65.6 ± 18.2 (17.1–98.5) years. The distribution of age was positively skewed compared with a normal distribution. The mean height was 170.9 ± 9.7 cm and the body mass index was 26.4 ± 5.6 kg/m^2. At admission, atrial fibrillation was present in 33 (17%) patients, hypertension was present in 67 (34%) patients, 36 (18%) had known diabetes mellitus, and 20 (10%) had established heart failure. In total, cardiovascular disease defined as either angina pectoris, prior myocardial infarction, prior stroke, or established peripheral arterial disease was present in 71 (36%) of the patients. There were no significant differences in the basic characteristics of the 199 participants included in the study and the 247 participants not included in the study, but who were admitted to the hospital the days when the six residents performing PHHE examinations were on duty.

Table 1 Basic characteristics of the 199 study participants

	Mean ± SD (range)[a]
Age, years	65.6 ± 18.2 (17.1–98.5)
Male, *n* (%)	107 (53.8)
Height, cm	170.9 ± 9.7 (150–196)
Body mass index, kg/m^2	26.4 ± 5.6 (12–45)
Systolic blood pressure, mmHg	143.9 ± 28.6 (74–245)
Diastolic blood pressure, mmHg	75.0 ± 15.6 (24–120)
Heart rate, bpm	82.8 ± 22.6 (40–160)
Atrial fibrillation, *n* (%)	33 (16.6)
Known hypertension, *n* (%)	67 (33.7)
Known diabetes, *n* (%)	36 (18.1)
Known myocardial infarction, *n* (%)	32 (16.1)
Known angina, *n* (%)	17 (8.5)
Known heart failure, *n* (%)	20 (10.1)
Known peripheral vessel disease, *n* (%)	7 (3.5)
Known stroke, *n* (%)	35 (17.6)
Known cardiovascular disease, *n* (%)	71 (35.7)
Known cancer, *n* (%)	16 (8.0)

[a]Data are presented as mean ± SD (range) unless otherwise specified.

Pocket-size hand-held echocardiography

The time consumption of the examination, including large vessels, was median (range) 5.7 (1.6–19.9) min. Each resident performed a median (interquartile range) of 27 (19–46) examinations. *Table 2* shows the feasibility of PHHE. The left-ventricular (LV) function was assessed to satisfaction in nearly all of the patients (97%) and the pericardial space in all patients. The aortic and atrioventricular valves were assessed in at least 76% and the pulmonary valve in <50% of the patients. The vena cava inferior was assessed to satisfaction in 77% and the abdominal aorta in 50% of the population. This is also illustrated in *Figure 1*.

A total of 133 and 74 patients underwent high-end echocardiography and radiographic (CT or ultrasound) reference imaging, respectively. In total, 186 (93%) patients underwent reference imaging (*Figure 2*). For the different indices of cardiac structure or function, the available numbers of validated examinations are shown in *Tables 3* and *4*. *Table 3* shows the correlations of semi-quantitative assessment of cardiovascular structures and function indices between PHHE and standard echocardiography. The classification of global left-ventricular function, pleural, and pericardial effusion showed very strong correlation with standard diagnostic procedures (Spearman's $r \geq 0.83$, with variations between residents 0.70–0.93, 0.54–1.0, and 0.81–1.0, respectively). Regional left-ventricular function showed moderate correlation, $r = 0.60$ (variation between residents 0.53–0.61). The classification of

Table 2 Feasibility of point-of-care pocket-size echocardiography

Anatomic structure	Assessed to satisfaction (%)
Left ventricle	194 (97)
Right ventricle	172 (86)
Pericardium	199 (100)
Left atrium	173 (87)
Mitral valve	177 (89)
Aortic valve	171 (86)
Pulmonary valve	97 (49)
Tricuspid valve	152 (76)
Abdominal aorta	99 (50)
Vena cava inferior	154 (77)
Pleura	190 (95)

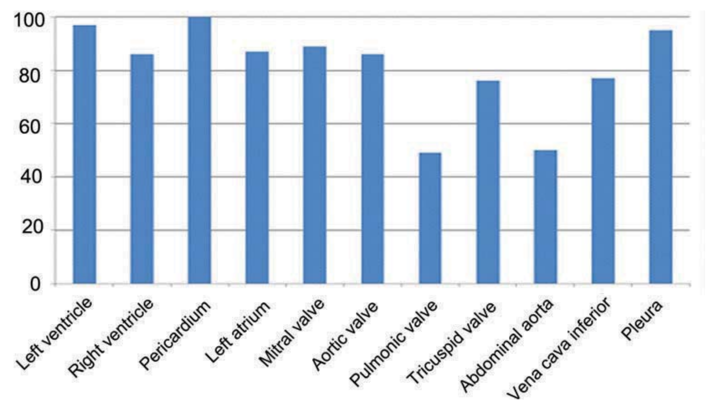


Figure 1 Feasibility of point-of-care pocket-size echocardiography. Feasibility (%) of the different cardiovascular structures when pocket-size echocardiography was performed by residents. The examinations of the different structures were judged by the residents as feasible if they were able to quantify the specific cardiac structures or function indices based on the recordings.

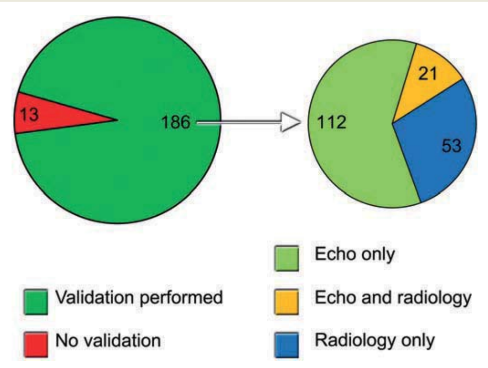


Figure 2 Validation of PHHE. Illustration of the number of patients that were validated with reference imaging (left) and by what kind of reference imaging (right). Echo, echocardiography.

aortic valve calcification/stenosis and regurgitation showed strong correlation with $r = 0.67$ (variation between residents 0.29–0.93) and $r = 0.68$ (variation between residents 0.33–1.0), respectively. Regurgitation of the atrioventricular valves showed moderate-to-strong correlations, $r = 0.53$ (variation between residents 0.34–0.80) for mitral and $r = 0.61$ (variation between residents 0.21–0.78) for tricuspid regurgitation, so did the degree of dilatation of the LA ($r = 0.61$) (variation between residents 0.23–0.76). No serious findings were missed. PHHE correlated strongly with standard diagnostics with respect to detect abdominal aortic aneurysms, $r = 0.70$. No aneurysms were missed, but there was one false positive diagnosis where the measurement of the aorta was 32 mm by PHHE and 28 mm by the abdominal CT. *Figure 3* illustrates the reproducibility data of the abdominal aortic diameter. The maximal diameter of the inferior vena cava correlated only moderately with high-end echocardiography, Pearson's $r = 0.45$. *Figure 4* illustrates the total number of misclassifications of global and regional

Table 3 Correlations of semi-quantitative classification of echocardiographic indices of pocket-size echocardiography and reference method

	n total	*n* pathology	*R*	95% CI
Global systolic function, left ventricle	129	26	0.83	0.71–0.93
Apparent regional dysfunction, left ventricle	129	22	0.60	0.39–0.78
Global systolic function, right ventricle	115	10	0.44	0.10–0.72
Size of left atrium	117	68	0.61	0.48–0.72
Aortic calcification and stenosis	119	37	0.67	0.52–0.80
Aortic regurgitation	117	27	0.68	0.52–0.82
Mitral regurgitation	123	54	0.53	0.37–0.68
Tricuspid regurgitation	107	49	0.61	0.45–0.74
Pericardial effusion	131	4	0.86	0.57–1.00
Pleural effusion	151	20	0.83	0.67–0.94
Abdominal aorta	52	2	0.70	0.49–1.00
Inferior vena cava[a]	94		0.45	0.24–0.62

Data presented as correlation coefficient (*r*) with 95% confidence interval achieved by bootstrapping.
n total, the total number who underwent both PHHE and reference imaging; *n* pathology, total number with the described pathology.
[a]Continuous variable, analysed by Pearson's correlation, all others analysed by Spearman's rank correlation.

Table 4 **Sensitivity, specificity, positive, and negative predictive value of point-of-care pocket-size echocardiography to detect at least moderate pathology compared with reference method**

	n total	*n* pathology	Sensitivity	Specificity	PPV	NPV
LV dysfunction	129	30	92	94	80	98
RV dysfunction	115	10	40	97	57	94
LA enlargement	117	68	62	94	93	64
Aortic regurgitation	117	27	82	89	69	94
Aortic stenosis/calcification	119	37	76	88	74	89
Mitral regurgitation	123	48	71	81	71	81
Tricuspid regurgitation	107	49	65	90	84	75

n total, the total number who underwent both PHHE and reference imaging; *n* pathology, total number with the described pathology; LV, left ventricle; RV, right ventricle; LA, left atrium; PPV, positive predictive value; NPV, negative predictive value.

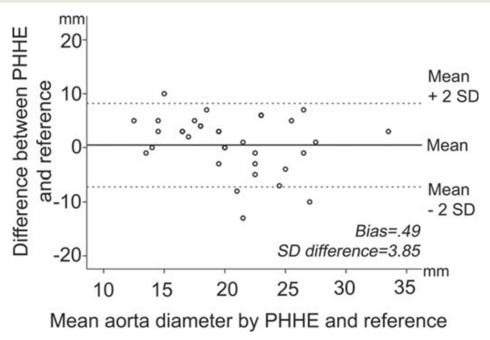


Figure 3 Bland–Altman plot for the assessment of the abdominal aortic diameter using PHHE and reference imaging. Reproducibility for the assessment of the diameter of the abdominal aorta. Bland-Altman plot of difference between PHHE and reference imaging by the mean of the measurements.

ventricular and valvular pathology by PHHE compared with the reference. For the quantification of LV global function, LA size, and aortic stenosis, respectively, 7, 2, and 5% of the misclassifications were two degrees; all other misclassifications were only one degree. *Figure 5* shows clinical examples of PHHE compared with reference method, and a clinical example is given in Supplementary material online, *Videos S1* and *S2*.

Table 4 shows the sensitivity, specificity, positive, and negative predictive values of PHHE to detect at least moderate pathology. There was high specificity and negative predictive values of detecting left- and right-ventricular dysfunction and aortic-valve pathology. On the contrary, the lower sensitivity and positive predictive values for the assessment of right-ventricular function and left-atrial size are mainly caused by some underestimation of pathology.

Discussion

Our study demonstrates that medical residents in <6 min can perform a bedside ultrasound examination of the heart, pleural space, and the abdominal great vessels after a 3 months training period and get reliable and clinically important diagnostic information beyond the standard physical examination.

The patients were included solely during the time when the participating residents were on call and represent otherwise an unselected population in our department. The population characteristics are also in line with patient characteristics from previous studies in similar settings.[10,17,18]

PHHE has in several studies showed a high feasibility and accuracy when performed by experts.[6–9] Galderisi *et al.*[8] showed slightly lower sensitivity and specificity when trainees performed PHHE compared with experts. Panoulas *et al.*[19] showed improved diagnostic accuracy when medical students and junior doctors added a PHHE examination to history, physical examination, and ECG findings. Our results are in line with their findings when PHHE is performed by non-experts. The feasibility is overall very good, 75–100% for all structures except the pulmonic valve and the abdominal aorta which were assessed to satisfaction in approximately one-half of the patients. Inexperienced users may be less able to provide optimal image quality and need better image quality to be able to interpret the recordings compared with expert users, but we have no data to support this hypothesis. The abdominal aorta was assessed in a relatively small number of patients compared with expert studies.[7,20] This may partly be explained by the fact that the residents did not register the aorta as assessed unless the entire length of the aorta was satisfactorily assessed. Secondly, patients were non-fasting, thereby reducing abdominal image quality, and BMI was ~2 kg/m^2 higher in whom the abdominal aorta was not assessed ($P < 0.001$). Nonetheless, there may have been too little focus on examining the great vessels during the training period.

The assessment of the global left-ventricular function and the pericardial and pleural space compared excellently with standard diagnostics. These are crucial issues in the cardiovascular ultrasound examination.[21] The classification/assessment of valvular function showed moderate-to-strong correlation and we found high specificity and high negative predictive values for detecting at least moderate valvular pathology. Importantly, no serious findings were missed, neither according to aortic valve pathology or regurgitation of the atrioventricular valves. However, there was

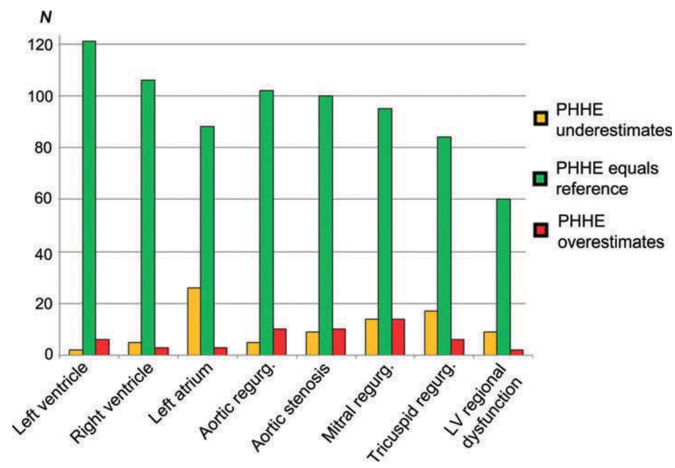


Figure 4 Classification of ventricular and valvular pathology by PHHE compared with reference echocardiography. The agreement of PHHE and reference echocardiography in the quantification of ventricular and valvular pathology is illustrated. Over- and underestimation is the total numbers of misclassifications. In total, only 2% were misclassified by two degrees, the rest by one degree. LV, left ventricle; *N*, numbers; regurg, regurgitation.

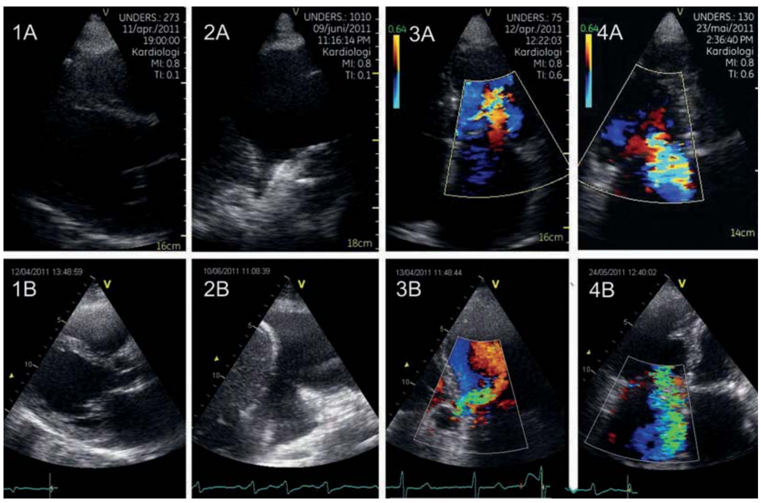


Figure 5 Cases illustrating the comparison of PHHE with reference method. (*A*) shows images from the pocket-size device, while (*B*) shows images from the high-end Vivid 7 scanner (GE Vingmed Ultrasound). 1 (*A* and *B*): 54-year-old man with principal diagnosis of liver cirrhosis changed to dilated cardiomyopathy after PHHE. 2 (*A* and *B*): 70-year-old man with known heart failure concluded to be decompensated after finding the shown significant amount of pleural effusion, dilated vena cava inferior, and reduced LV function. 3 (*A* and *B*): 75-year-old man referred with stroke where PHHE revealed an unknown moderate aortic regurgitation (without importance for the acute treatment). 4 (*A* and *B*): 88-year-old woman admitted with heart failure. PHHE revealed dilated ventricles, the shown large tricuspid regurgitation, pleural effusion, and ascites due to hypervolaemia.

some under- and overestimation of both ventricular dysfunction and valvular pathology. This may be explained by less experienced users, a very sensitive colour mode, and the lack of spectral Doppler in the PHHE devices. We find the presented degree of misclassification of aortic stenosis, in line with the presented, but less pronounced overestimation of aortic stenosis related to the lack of spectral Doppler in recent studies.[6,7] No moderate or severe aortic stenosis was missed. Atrioventricular valves regurgitations were missed more often compared with aortic regurgitations and this may be related to the higher number of atrioventricular regurgitations in the presented population. Due to moderate feasibility, the correlation of the aortic diameter was tested in only 52 patients and in these patients there was a strong agreement, and in the one misclassified, the difference was 4 mm. No aneurysms were missed by PHHE. The moderate agreement between PHHE and standard diagnostics in the assessment of the inferior vena cava may be explained by the period of time between PHHE and the standard echocardiography of median 21 h. Physiological variations and treatment effects may have influenced the results.[22] In addition, measurements of the size of the LA and vena cava inferior may be influenced by the fact that the pocket-size device lacks ECG-cables and there are limited opportunities to ensure the correct timing in the cardiac or respiratory cycles.

Taking a thorough medical history and performing a physical examination will remain the cornerstones in the diagnostic procedure, but there is a need for improvement in diagnostic accuracy to decrease medical errors.[1,23] PHHE is an excellent tool to provide further diagnostic information. As stated by the EACVI (former EAE) the users level of competence is very important in these devices.[24] Experienced ultrasonographers can start using PHHE without limitations. In less-experienced users, targeted education and a training period are necessary and PHHE should be used only for targeted examinations depending on the skills of the user.

Even in the hands of relatively inexperienced residents, PHHE provides feasible and reliable information at the point-of-care and improves the diagnostic precision without significant time delay. However, it is important to state that PHHE cannot replace the standard echocardiographic examination performed by experts in the echo lab. It should remain a bedside imaging tool which allows for quick and important information without losing valuable time.

Limitations

In the study period, 1076 emergency admissions to the medical department were recorded and 84 of these patients declined consent. Out of the 446 patients randomized to receive PHHE examination, only 199 actually received it. This is mainly explained by busy working hours, hospital logistics, and the residents being informed to have a priority on standard diagnostics and treatment of patients.

The study was a single-centre study with a limited number of participating residents and patients. Consecutive patients were included and critical diagnosis such as aortic dissection and cardiac tamponade were not registered during the inclusion period. It is important to emphasize that in such cases, PHHE may offer a fast track to the correct diagnosis,[10] but negative findings must not rule out further diagnostic tests if the clinician still suspects specific conditions.

Conclusion

By adding a point-of-care PHHE examination lasting <6 min, medical residents were able to obtain reliable information of important cardiac structures and great vessels in patients admitted to a medical department. Thus, a focused examination with PHHE performed by residents, after a targeted training period have the potential to improve in-hospital diagnostics and care.

Supplementary material

Supplementary material is available at *European Heart Journal – Cardiovascular Imaging* online.

Acknowledgements

We thank all the participating doctors, nurses, and secretarial staff at Levanger hospital for their invaluable assistance with the inclusion and data collection for this study. OCM, GNA, HD, and BOH hold positions at MI Lab, a Centre of Research-based Innovation that is funded by the Research Council of Norway and industry. One of the industry partners is GE Vingmed Ultrasound. The Centre has a total budget of 124 million NOK for the 8 years period from 2007 to 2014, and the contribution from GE Vingmed Ultrasound to this budget is 7 million NOK (6%).

Conflict of interest: none declared.

Funding

This study is funded by the Nord-Trøndelag Health Trust, Norway and the Norwegian University of Science and Technology, Norway.

References

1. Burton JL, Underwood J. Clinical, educational, and epidemiological value of autopsy. *Lancet* 2007;**369**:1471–80.
2. Roelandt JR. Ultrasound stethoscopy: a renaissance of the physical examination? *Heart* 2003;**89**:971–3.
3. Roelandt JR. Ultrasound stethoscopy. *Eur J Intern Med* 2004;**15**:337–47.
4. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med* 2011;**364**: 749–57.
5. Dalen H, Haugen BO, Graven T. Feasibility and clinical implementation of hand-held echocardiography. *Expert Rev Cardiovasc Ther* 2013;**11**:49–54.
6. Prinz C, Voigt JU. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. *J Am Soc Echocardiogr* 2011;**24**: 111–6.
7. Andersen GN, Haugen BO, Graven T, Salvesen O, Mjolstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. *Eur J Echocardiogr* 2011;**12**:665–70.
8. Galderisi M, Santoro A, Versiero M, Lomoriello VS, Esposito R, Raia R *et al.* Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples Ultrasound Stethoscope in Cardiology) study. *Cardiovasc Ultrasound* 2010;**8**:51.
9. Prinz C, Dohrmann J, van Buuren F, Bitter T, Bogunovic N, Horstkotte D *et al.* Diagnostic performance of handheld echocardiography for the assessment of basic cardiac morphology and function: a validation study in routine cardiac patients. *Echocardiography* 2012;**29**:887–94.
10. Mjolstad OC, Dalen H, Graven T, Kleinau JO, Salvesen O, Haugen BO. Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department. *Eur J Intern Med* 2012;**23**:185–91.
11. Skjetne K, Graven T, Haugen BO, Salvesen O, Kleinau JO, Dalen H. Diagnostic influence of cardiovascular screening by pocket-size ultrasound in a cardiac unit. *Eur J Echocardiogr* 2011;**12**:737–43.

12. Aase SA, Snare SR, Dalen H, Stoylen A, Orderud F, Torp H. Echocardiography without electrocardiogram. *Eur J Echocardiogr* 2011;**12**:3–10.
13. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA *et al.* Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* 2005;**18**:1440–63.
14. Baumgartner H, Hung J, Bermejo J, Chambers JB, Evangelista A, Griffin BP *et al.* Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. *J Am Soc Echocardiogr* 2009;**22**:1–23; quiz 101–2.
15. Lancellotti P, Moura L, Pierard LA, Agricola E, Popescu BA, Tribouilloy C *et al.* European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease). *Eur J Echocardiogr* 2010;**11**:307–32.
16. Lancellotti P, Tribouilloy C, Hagendorff A, Moura L, Popescu BA, Agricola E *et al.* European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 1: aortic and pulmonary regurgitation (native valve disease). *Eur J Echocardiogr* 2010;**11**:223–44.
17. de Groot-de Laat LE, ten Cate FJ, Vourvouri EC, van Domburg RT, Roelandt JR. Impact of hand-carried cardiac ultrasound on diagnosis and management during cardiac consultation rounds. *Eur J Echocardiogr* 2005;**6**:196–201.
18. Vourvouri EC, Koroleva LY, Ten Cate FJ, Poldermans D, Schinkel AF, van Domburg RT *et al.* Clinical utility and cost effectiveness of a personal ultrasound imager for cardiac evaluation during consultation rounds in patients with suspected cardiac disease. *Heart* 2003;**89**:727–30.
19. Panoulas VF, Daigeler AL, Malaweera AS, Lota AS, Baskaran D, Rahman S *et al.* Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. *Eur Heart J Cardiovasc Imaging* 2013;**14**:323–30.
20. Dijos M, Pucheux Y, Lafitte M, Reant P, Prevot A, Mignot A *et al.* Fast track echo of abdominal aortic aneurysm using a real pocket-ultrasound device at bedside. *Echocardiography* 2012;**29**:285–90.
21. Martin LD, Mathews S, Ziegelstein RC, Martire C, Howell EE, Hellmann DB *et al.* Prevalence of asymptomatic left ventricular systolic dysfunction in at-risk medical inpatients. *Am J Med* 2013;**126**:68–73.
22. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990;**66**:493–6.
23. Combes A, Mokhtari M, Couvelard A, Trouillet JL, Baudot J, Henin D *et al.* Clinical and autopsy diagnoses in the intensive care unit: a prospective study. *Arch Intern Med* 2004;**164**:389–92.
24. Sicari R, Galderisi M, Voigt JU, Habib G, Zamorano JL, Lancellotti P *et al.* The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. *Eur J Echocardiogr* 2011;**12**:85–7.

IMAGE FOCUS

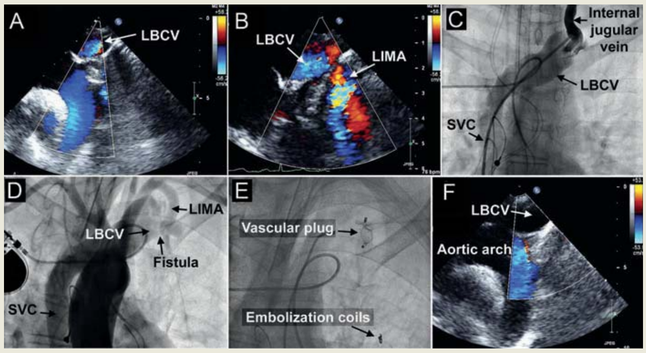
doi:10.1093/ehjci/jet114
Online publish-ahead-of-print 3 July 2013

I can hear it, but where is it coming from? A case of iatrogenic arteriovenous fistula after pacemaker lead extraction

Kevin C. Ong, Samuel J. Asirvatham, Charanjit S. Rihal, Donald J. Hagler, and Sorin V. Pislaru*

Division of Cardiovascular Diseases, Department of Medicine, Mayo Clinic, 200 1st Street SW, Rochester, MN 55905, USA

* Corresponding author. Tel: +1 5072842511; Fax: +1 5072667929, Email: pislaru.sorin@mayo.edu



A 54-year-old woman was referred to our institution for the assessment of a loud continuous murmur detected 3 years after pacemaker lead extraction. She previously had a dual-chamber pacemaker implanted for symptomatic sinus node dysfunction. Owing to recurrent and severe symptomatic phrenic nerve pacing, she underwent laser lead extraction. The procedure was complicated by a tear at junction of the superior vena cava (SVC) and right atrium requiring surgical repair. All endocardial pacing leads were removed and an epicardial right atrial pacing lead was implanted.

The source of continuous murmur could not be identified on initial transthoracic echocardiography (TTE). Auscultation revealed that the continuous murmur was loudest in the left upper chest. Additional TTE in the suprasternal area revealed continuous high flow in the left brachiocephalic vein (LBCV; *Panel A*, Supplementary data online, *Video S1*) and the left internal mammary artery (LIMA; *Panel B*) due to a communication between these vessels (Supplementary data online, *Video S2* and *Image S1*). Venogram of the LBCV showed marked dilation with contrast reflux in the left internal jugular vein (*Panel C*, Supplementary data online, *Video S3*); oxygen saturation step up to 90% in the SVC was consistent with the arteriovenous shunt. Aortic angiography confirmed a connection between the LIMA and LBCV (*Panel D,* Supplementary data online, *Video S4*). The fistula was closed with an Amplatz® vascular plug to the proximal LIMA and Tornado® embolization coils to the distal LIMA (*Panel E*, Supplementary data online, *Video S5*). There was no residual shunt flow in LBCV (*Panel F*, Supplementary data online, *Video S6*).

Arteriovenous fistula between the LIMA and LBCV is a rare complication of laser lead extraction. In this case, auscultation-guided TTE played a key role in establishing the extracardiac origin of the murmur.

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

Paper 3

Diagnostic Influence of Routine Point-of-Care Pocket-size Ultrasound Examinations Performed by Medical Residents

Garrett N. Andersen, MD, Torbjørn Graven, MD, Kyrre Skjetne, MD, Ole C. Mjølstad, MD, PhD, Jens O. Kleinau, MD, Øystein Olsen, MD, Bjørn O. Haugen, MD, PhD, Håvard Dalen, MD, PhD

Article includes CME test

Objectives—We aimed to investigate the potential benefit of adding goal-directed ultrasound examinations performed by on-call medical residents using a pocket-size imaging device in patients admitted to a medical department.

Methods—A total of 992 emergency admissions to the medical department at a nonuniversity hospital in Norway were included. Patients admitted on dates with an on-call medical resident randomized to use a pocket-size imaging device were eligible for pocket-size cardiac and abdominal ultrasound examinations or standard care. The cardiac examination included estimation of right and left ventricular sizes and global systolic function and regional left ventricular systolic function, evaluation for pleural and pericardial effusion, and valvular disease. The abdominal examination looked for signs of gross abnormalities of the liver, gallbladder, abdominal aorta, inferior vena cava, and urinary system. Six of 12 medical residents with limited ultrasound experience were randomized to perform the examinations. Diagnostic corrections were made, and findings were confirmed by reference standard diagnostics.

Results—A total of 199 patients were examined. Median times used were 5.7 minutes for the cardiac examination and 4.7 minutes for the abdominal examination. In 13 patients (6.5%), the examination resulted in a major change in the primary diagnosis. In 21 patients (10.5%), the diagnosis was verified, and in 48 (24.0%), an additional important diagnosis was made.

Conclusions—By implementing pocket-size ultrasound examinations that took less than 11 minutes to the usual care, we corrected, verified, or added important diagnoses in more than 1 of 3 emergency medical admissions. Point-of-care examinations with a pocket-size imaging device increased medical residents' diagnostic accuracy and capability.

Key Words—diagnosis; echocardiography; general medicine; health economics; point-of-care ultrasound

Received January 28, 2014, from Levanger Hospital, Nord-Trøndelag Health Trust, Levanger, Norway (G.N.A., T.G., K.S., J.O.K., Ø.O., H.D.); Medical Imaging Laboratory (G.N.A., O.C.M., B.O.H., H.D.), Department of Circulation and Medical Imaging (G.N.A., O.C.M., B.O.H., H.D.), and Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, Trondheim, Norway; and Clinic of Cardiology, St Olav Trondheim University Hospital, Trondheim, Norway (O.C.M., B.O.H.). Revision requested March 7, 2014. Revised manuscript accepted for publication July 25, 2014.

We thank all of the participating physicians, nurses, and secretarial staff at Levanger Hospital for their invaluable assistance with the inclusion and data collection for this study. The Norwegian University of Science and Technology and Nord-Trøndelag Health Trust funded this study. Drs Andersen, Mjølstad, Haugen, and Dalen hold positions at the Medical Imaging Laboratory, Norwegian University of Science and Technology, a Center of Research-Based Innovation that is funded by the Research Council of Norway and industry. One of the industry partners is GE Vingmed Ultrasound.

Address correspondence to Garrett N. Andersen, MD, Medical Imaging Laboratory and Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Postboks 8905, 7491 Trondheim, Norway.

E-mail: garrett.andersen@gmail.com

Abbreviations
LV, left ventricular; RV, right ventricular

doi:10.7863/ultra.34.4.627

With the aid of Laennec and his stethoscope, the European diagnosticians of the 19th century paved the way for the art and science of clinical and bedside diagnosis. The development of newer and more advanced diagnostic procedures and techniques has increased diagnostic accuracy and in many cases removed the diagnosis from the bedside and clinician (ie, the patient's point of care) to the radiologic, echocardiographic, and biochemical laboratories. As a consequence, a decline in the clinical skills of present and future physicians has emerged.[1–3]

Despite the advances in expensive high-tech diagnostic and therapeutic agents, major diagnostic errors continue to be found in up to 30% of patients at autopsy.[4–6] Thus, there is an obvious need for an efficient increase in clinical diagnostic accuracy. Point-of-care ultrasound, defined as ultrasound brought to the patient and used by the provider in real time[7] with a pocket-size imaging device, has been shown to rapidly and cost-effectively improve diagnostic accuracy in the hands of experts.[8–16]

In clinical practice, nonexperts are often the first to see patients, and the usefulness of point-of-care pocket-size ultrasound examinations performed by less-experienced users remains uncertain. Thus, we aimed to study the diagnostic influence of routinely adding a focused cardiac and abdominal examination with a pocket-size imaging device, performed by medical residents, on emergency admissions to a medical department and assess for an increased diagnostic influence in patients at higher cardiovascular risk.

Materials and Methods

Medical Residents

To ensure optimal training, half of the medical residents at Levanger Hospital (6 of 12 residents) were randomly selected by a draw for inclusion in the study 3 months before the study began. They had varying, although limited, degrees of ultrasound experience.

Study Population

All patients admitted to the Department of Medicine at the nonuniversity Levanger Hospital were included from April 4 to June 23, 2011, with a pause in study inclusions during Easter holidays. A flowchart illustrating the numbers available for randomization and pocket-size ultrasound examinations in the study is shown in Figure 1. The only exclusion criterion was an inability or unwillingness to provide informed consent. Specifically, no patients were excluded because of poor image quality or the level of cardiovascular risk. Patients randomized to pocket-size imaging with an urgent need of advanced imaging procedures or specific treatment were included if the pocket-size ultrasound examination did not cause a delay in the planned investigation or procedure. The Department of Medicine includes separate wards for cardiology, nephrology, gastroenterology, hematology and infectious diseases, pulmonary diseases, and geriatric and cerebrovascular diseases.

Patients were eligible to receive pocket-size ultrasound examinations on the basis of the time and date of admission. Patients were not informed of whether they would receive a pocket-size ultrasound examination on study inclusion. Patients admitted on dates with an on-call medical resident randomized to use a pocket-size imaging device were eligible for pocket-size ultrasound examinations. Those admitted on all other dates were seen by residents randomized to not use a pocket-size imaging device and thus were included in the control group. Patients eligible for pocket-size ultrasound examinations who did not receive them were also allocated to the control group. Patients were admitted from the hospital emergency department, where they were triaged according to signs and symptoms. They were examined by a medical intern or resident and were provided a provisional diagnosis based on standard history taking, physical examinations, laboratory tests, and goal-directed imaging (not including ultrasound).

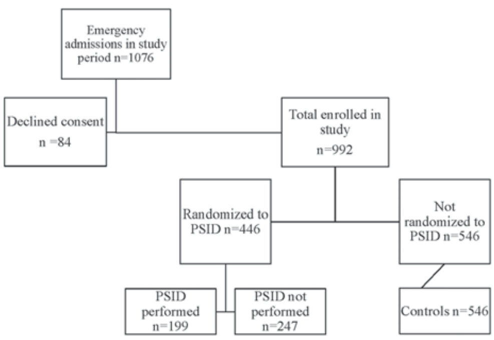
After the initial admission workup, the on-call medical resident regularly reviewed the patients. The pocket-size ultrasound examinations were performed at this time in addition to the standard care provided by the medical resident. The residents were instructed to perform as many pocket-size ultrasound examinations as possible on emergency admissions while on duty.

Written informed consent was obtained from all patients in the case and control groups. The study was registered at ClinicalTrials.gov (NCT01331187), approved by the Regional Committee for Medical and Health Research Ethics, and conducted according to the Declaration of Helsinki.

Training and Education of Medical Residents

The medical residents received 4 hours of formal didactic lectures from a cardiologist and radiologist on the physics, pitfalls, and limitations of ultrasound, as well as a theoretical map on how to perform the examinations. Normal and

Figure 1. Study population and randomization. PSID indicates pocket-size imaging device.



pathologic findings were demonstrated. The focus was on scanning techniques, image acquisition, and interpretation. They all had access to an in-house imaging library with illustrations of both anatomy and abnormalities, including how to obtain similar views and images, as well as how to interpret them for clinical decision making. Each participating resident was allocated a personal supervisor; all supervisors were specialists in internal medicine and cardiology and experienced in abdominal and cardiac ultrasound. The pocket-size ultrasound study was considered feasible if the resident was able to obtain the specific image (organ, structure, or abnormality) and provide an interpretation. Subsequently, the residents were encouraged to perform as many examinations as possible or at least 100 abdominal and cardiac examinations with a high-end mobile or pocket-size ultrasound device before the study start. The median actual number performed before the study start was 95 (interquartile range, 80–225) examinations; a median of 32.5 (interquartile range, 20–85) examinations had hands-on supervision by a relevant specialist or advanced trainee.

Pocket-size Ultrasound Examination

The ultrasound examination was performed bedside with a pocket-size imaging device (Vscan; GE Vingmed Ultrasound, Horten, Norway). The device measures 135 × 73 × 28 mm and weighs 390 g, including a phased array probe. Two-dimensional grayscale and live color Doppler imaging can be performed. The image sector for echocardiographic imaging is 75°. The bandwidth ranges from 1.7 to 3.8 MHz and is automatically adjusted. Storage and looping of a cardiac cycle are possible without an electrocardiographic signal, and looping of other structures is predefined and limited to 2 seconds. The device has separate modes optimized for cardiac and abdominal examinations. Patient identification was performed by using voice recording and an automatically assigned examination number. All images and recordings were saved on the device's micro-SD card and later transferred to a computer by commercial software (Gateway; GE Vingmed Ultrasound).

A standardized examination protocol was used. The bedside (point-of-care) cardiovascular ultrasound examination was performed with patients in the left-lateral decubitus position, supine position, or both. The time used for the examination was calculated as the time from the start to the end of the examination. Assessments of left ventricular (LV) global and regional function, right ventricular (RV) size and function, valvular anatomy and function, and the pericardium were done from parasternal long- and short-axis and apical 4-chamber, 2-chamber, and long-axis views. Global LV and RV functions were classified by visual assessment as normal/near normal, moderate dysfunction, or severe dysfunction. Quantification of LV function corresponded to an ejection fraction of greater than 45%, 30% to 45%, or less than 30%, respectively. In addition, systolic atrioventricular plane excursion was used for quantification of both LV and RV functions. The sizes of the ventricles influenced the judgment, and for RV function quantification, the diastolic shift of the intraventricular septum to the left was included. Regional LV dysfunction was classified as present or not.

Valvular disease and dysfunction were 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 regurgitation was based on the color flow jet and the sizes and functions of the adjacent chambers. Pericardial effusion was classified as present or not. The size of the left atrium was measured online on grayscale parasternal long-axis images and converted to semiquantitative measures. An attempt was made to do a measurement of the left atrium at end systole. The abdominal aorta and inferior vena cava were assessed from the subcostal position. The abdominal aorta was assessed distally to the bifurcation and classified as the presence or absence of an abdominal aortic aneurysm, depending on whether the diameter exceeded 35 mm. The end-expiratory inferior vena cava diameter was measured within 2 cm from the right atrial orifice. All dimension measurements were done on the pocket-size imaging device. With patients in a supine or upright position, the pleura was assessed from left and right thoracic dorsolateral views, and the amount of pleural effusion was classified as none, small to moderate, or substantial.[17]

The liver, gallbladder, and kidneys were assessed from a supine position. The liver and gallbladder were classified as normal or abnormal, where sonographic evidence of cholecystitis, cholecystolithiasis, or intrahepatic tumors are examples of abnormal findings. The kidneys were classified as normal, evidence of hydronephrosis, or other disease.

Diagnostic corrections to initial evaluations were made after the pocket-size ultrasound examination. To verify findings, all patients with diagnostic changes and reported pathologic findings were referred for standard diagnostic procedures (ie, a complete echocardiographic examination, an abdominal ultrasound examination, computed tomography, or magnetic resonance imaging) according to the medical condition suspected. In addition, the study committee daily selected 1 or 2 patients at random, with reportedly normal pocket-size imaging findings, to undergo reference echocardiographic or abdominal ultrasound examinations, or both to assess the degree of false-negative findings. All residents performing pocket-size ultrasound examinations had access to clinical information, including the preliminary diagnosis and any imaging findings. To avoid impeding hospital work flow, radiologists responsible for reference imaging of patients with positive and negative findings were not blinded to the results of the pocket-size ultrasound examinations. However, the cardiologists performing the high-end reference imaging procedures were blinded to the results of the pocket-size ultrasound examinations but not to the data from the medical history or physical examination. For analyses of the patients who underwent both echocardiographic and radiographic examinations, the radiologists' classifications of pleural effusion (computed tomography or ultrasound imaging) and the size of the abdominal aorta were used in cases with dual measurements.

Clinical Influence of Routine Pocket-size Ultrasound

All patients' diagnostics were judged by an end-point committee consisting of 2 in-house and 1 external (St Olav Trondheim University Hospital) clinician, all of whom were specialists in internal medicine and cardiology experienced in echocardiography and abdominal ultrasound. The committee members were blinded to the decisions of the other members, and each individually reviewed all of the cases. The diagnostic usefulness of the pocket-size imaging device was judged on an individual basis, using medical journals and considering all relevant diagnostic tests performed before examination with the pocket-size device. False-positive and -negative diagnoses did not count as diagnostically useful. The influence of pocket-size ultrasound was divided into the following categories: (1) the principal diagnosis was changed; (2) the principal diagnosis was confirmed; (3) an additional diagnosis that was important for in-hospital treatment or follow-up was added; (4) an additional diagnosis that did not influence treatment or follow-up; and (5) no change, verification, or additional diagnosis was made. In cases of disagreement (33 of 199), the majority of the committee had the preference. Specifically, findings from pocket-size ultrasound examinations that were already available in previous imaging reports were not considered of any diagnostic influence.

Statistics

The basic demographics are presented as mean ± standard deviation and range. Data not following a normal distribution are presented as median and interquartile range. The Mann-Whitney U test or Student's *t* test of independent samples was used for comparison of continuous variables between groups. Proportions between groups were analyzed by χ^2 statistics or the Fisher exact test. The Spearman correlation (r) was used for comparison of the quantification of pathologic findings between the pocket-size ultrasound and high-end echocardiographic or radiographic examinations. For comparison of normally distributed continuous variables, the Pearson correlation (r) was used. Data are presented as r values and 95% confidence intervals, with the 95% confidence intervals computed by bootstrapping.

To assess predictors of the influence of the pocket-size ultrasound examinations, logistic regression analyses were used. A change of the primary diagnosis or any diagnostic usefulness (change or verification of the primary diagnosis or an important additional diagnosis) was used as a dependent variable, and age and cardiovascular risk factors were included as independent variables. Increased risk was classified as present if the patients had any known cardiovascular disease, hypertension, or diabetes. The power estimate was greater than 80% for detecting a difference in a change of the primary diagnosis in 6% of a population sample of 200 at the 5% significance level (SPSS SamplePower; IBM Corporation, Armonk, NY). All statistical analyses were performed with SPSS version 20.0 software for Windows (IBM Corporation). $P < .05$ was considered significant.

Results

Population

Of 1076 emergency admissions to the Department of Medicine at Levanger Hospital, 84 were not willing or unable to give their consent. A total of 992 patients were included in the study; their basic demographics are shown in Table 1. Of these, 446 patients were eligible for pocket-size ultrasound examinations, as they were admitted on dates with an on-call medical resident randomized to use the pocket-size imaging device. A total of 199 patients were actually examined with the pocket-size imaging device by 1 of 6 on-call medical residents during the study period (Figure 1). The medical residents each performed a median of 28 (interquartile range, 24–46) pocket-size ultrasound examinations. The median time used for a complete pocket-size ultrasound examination was 10.6 minutes (interquartile range, 8.6–13.8 minutes), including 5.7 minutes for the cardiac examination and 4.7 minutes for the abdominal examination.

The mean age of the 199 patients (107 male and 92 female) who were examined with the pocket-size imaging device was 65.6 ± 18.0 years (range, 17–98 years), and the age distribution was positively skewed compared to a normal distribution. In this group, atrial fibrillation was present in 33 patients (17%) at admission; hypertension was present in 67 (34%); and 38 (19%) had known diabetes mellitus. Cardiovascular disease, which was defined as at least 1 of the following diagnoses: myocardial infarction, angina pectoris, heart failure, cerebrovascular disease, or peripheral vascular disease, was present in 91 patients (46%). Malignant disease was previously diagnosed in 16 patients (8%). Apart from the prevalence of known malignant disease, there were no significant differences between the study groups (Table 1).

Feasibility and Reliability

The ability to acquire and interpret the recordings showed high feasibility (≥83%) for most cardiac and abdominal structures but only 50% feasibility for the abdominal aorta. The correlations for semiquantitative assessment of cardiovascular and abdominal structures and function indices between pocket-size ultrasound and the reference methods were generally good, with strong to moderate correlations (Table 2). Further data on cardiovascular feasibility and reliability pertaining to the study population have recently been published.[18]

Diagnostic Influence of Pocket-size Ultrasound

In 69 patients (35%), pocket-size ultrasound was found to be of diagnostic influence as it changed, verified, or added an additional important diagnosis (Table 3 and Figure 2). Pocket-size ultrasound examinations resulted in a major change of the primary diagnosis in 13 patients (6.5%). The diagnosis was verified in 21 patients (10.5%), and in 48 (24%), an additional important diagnosis was made. An additional clinically unimportant diagnosis (defined as a new diagnosis not influencing treatment or generating further follow-up) was made in a further 25 patients (13%).

In several patients, the diagnostic yield was seen in more than 1 category (ie, 82 findings of diagnostic usefulness in 69 patients). Specifically, in nearly half of the patients for whom the diagnosis was verified by pocket-size ultrasound, an additional clinically important diagnosis was made. Similarly in one-third of patients who had their diagnosis changed by pocket-size ultrasound, an additional clinically important diagnosis was made. Four of 6 residents changed the primary diagnosis at least once (median, 1.5; interquartile range, 0–7; $P = .002$) after pocket-size ultrasound examinations, and all residents showed any diagnostic influence of pocket-size ultrasound (median 10; interquartile range, 6–27). The baseline characteristics, preliminary diagnoses, and pocket-size imaging findings for the patients in whom the primary diagnoses were changed are presented in Table 4. Specifically, heart failure, serious valvular disease, cholecystitis, malignancy, and hypovolemia were all examples of changed diagnoses. Examples of diagnoses that were verified by pocket-size ultrasound include heart failure, myocardial infarction, liver failure, malignancy and hypovolemia. Heart failure, hyper-

Table 1. Basic Demographics of the Study Participants

Parameter	PSID Received (n = 199)	Randomized to PSID but Not Received (n = 247)	P^a	Control Group (n = 546)	P^b
Age, y	64.8 ± 18.1 (17–98)	66.5 ± 19 (16–98)	.34	67.0 ± 17.7 (16–97)	.14
Women, n (%)	94 (47)	112 (45)	.69	246 (45)	.60
Systolic blood pressure, mm Hg	144 ± 29 (74–245)	141 ± 27 (68–217)	.33	145 ± 30 (65–237)	.66
Diastolic blood pressure, mm Hg	75 ± 16 (24–120)	74 ± 16 (31–120)	.54	76 ± 17 (33–152)	.37
Body mass index, kg/m^2	26.4 ± 5.6 (12–45)	25.6 ± 5.1 (14.2–38.1)	.58	26.2 ± 5.6 (14.4–51.6)	.67
Pulse, beats/min	83 ± 23 (40–160)	82 ± 20 (44–140)	.80	83 ± 21 (26–195)	.78
Temperature, °C	37.2 ± 0.8 (35.3–40.3)	37.3 ± 0.9 (35.0–40.3)	.67	37.2 ± 0.9 (35.1–40.9)	.55
Atrial fibrillation, n (%)	33 (17)	29 (13)	.31	71 (15)	.51
Hypertension, n (%)	67 (34)	64 (26)	.07	154 (28)	.15
Diabetes mellitus, n (%)	38 (19)	39 (16)	.36	97 (18)	.68
Myocardial infarction, n (%)	33 (17)	45 (18)	.65	88 (16)	.88
Angina pectoris, n (%)	18 (9)	30 (12)	.29	56 (10)	.63
Heart failure, n (%)	20 (10)	30 (12)	.49	73 (13)	.23
Peripheral vascular disease, n (%)	7 (4)	9 (4)	.94	32 (6)	.20
Cerebrovascular accident, n (%)	35 (18)	43 (17)	.96	81 (15)	.36
Malignancy, n (%)	16 (8)	38 (15)	.02	85 (16)	.008

Data are presented as mean ± SD (range) unless otherwise specified. PSID indicates pocket-size imaging device.
[a]Differences between pocket-size imaging examinations received and pocket-size imaging examinations randomized but not received.
[b]Differences between pocket-size imaging examinations received and the control group.

trophic obstructive cardiomyopathy, regional wall motion abnormalities, major valvular disease, a dilated ascending aorta, ascites, pericardial and pleural effusions, urinary retention, hypovolemia, and fluid overload are examples of additional important diagnoses. Examples of clinically unimportant additional diagnoses include minor valvular disease, gallstones, and simple renal cysts.

Age and the presence of increased cardiovascular risk differed significantly between those with change of the primary diagnoses and those with any diagnostic influence of pocket-size ultrasound compared to those without (Figure 2). The mean age was 10 years older in the group in which pocket-size ultrasound examinations changed or influenced the diagnosis ($P \leq .02$) compared to those without a change or influence to their diagnoses, with mean ages of 76 ± 12 years (range, 54–98 years) and 72 ± 16 years (range, 24–98 years) compared to 65 ± 18 years (range, 17–95 years) and 62 ± 19 years (range, 17–95 years). Age and the presence of cardiovascular risk predicted the influence of pocket-size ultrasound examinations, with 39% and 82% higher risk of changing the diagnosis per 10 years of age and the presence of cardiovascular risk factors, respectively (Table 5).

Table 2. Correlations for Semiquantitative Cardiovascular Structure and Function Indices and Abdominal Structures Between Pocket-size Ultrasound and Reference Methods

Parameter	Total, n	Pathologic, n	*r*	95% CI
LV global systolic function	129	26	0.83	0.71–0.93
Regional LV dysfunction	129	22	0.60	0.39–0.78
RV global systolic function	115	10	0.44	0.10-0.72
Left atrial size	117	68	0.61	0.48–0.72
Aortic calcification and stenosis	119	37	0.67	0.52–0.80
Aortic regurgitation	117	27	0.68	0.52–0.82
Mitral regurgitation	123	54	0.53	0.37–0.68
Tricuspid regurgitation	107	49	0.61	0.45–0.74
Pericardial effusion	131	4	0.86	0.57–1.00
Pleural effusion	151	20	0.83	0.67–0.94
Abdominal aorta	52	2	0.70	0.49–1.00
Inferior vena cava[a]	94	0	0.45	0.24–0.62
Kidneys	170	27	0.64	0.39–0.85
Liver and gallbladder	166	30	0.54	0.36–0.75

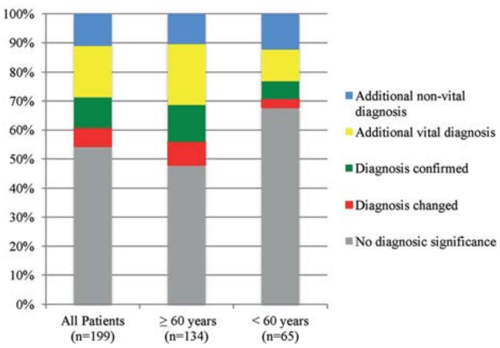
CI indicates confidence interval.
[a]Continuous variable, analyzed by Pearson correlation; all others analyzed by Spearman rank correlation.

Table 3. Diagnostic Influence of Goal-Directed Point-of-Care Cardiovascular and Abdominal Examinations With the Pocket-size Imaging Device

Parameter	% (n)	95% CI, %
Change of primary diagnosis	6.5 (13)	3–10
Verification of primary diagnosis	10.5 (21)	6–15
Important additional diagnosis[a]	24.0 (48)	18–30
Unimportant additional diagnosis[b]	12.5 (25)	8–17
No diagnostic use	54.0 (108)	47–61

CI indicates confidence interval.
[a]Diagnosis influencing treatment or follow-up: eg, heart failure, hypertrophic obstructive cardiomyopathy, regional wall motion abnormalities, major valvular disease, dilated ascending aorta, ascites, pericardial and pleural effusions, urinary retention, hypovolemia, and fluid overload.
[b]Diagnosis not influencing treatment or follow-up: eg, minor valvular disease, gallstones, and simple renal cysts.

Figure 2. Diagnostic usefulness of routinely adding cardiovascular and abdominal examinations with a pocket-size imaging device in all patients and specifically in those older and younger than 60 years.



Discussion

By routinely adding a goal-directed pocket-size ultrasound examination of approximately 11 minutes to the standard physical examination, medical residents changed, verified, or added a new clinically important diagnosis in more than one-third of patients (35%). The primary diagnosis alone was changed in 6.5% of patients.

The population was randomly selected on the basis of preset days when participating medical residents were on call. The study was conducted at the bedside by busy medical residents under suboptimal conditions on emergency admissions to the medical department. The distribution was positively skewed, and the baseline demographics were similar to those of recent studies, implying that the population reflects the usual patient population of a general medical department.[11,12,19] We suggest that the data were less influenced by selection biases, as only the prevalence of known malignancy differed significantly between the groups.

Many of the diagnostic corrections presented in Table 4 immediately influenced further treatment of the patients. Several of the cases would probably have been clarified during the hospital stay or at outpatient follow-up, but a correct diagnosis should ideally be made as early as possible. Thus, we hypothesize that a quick pocket-size ultrasound examination can increase the quality of care while saving time and possibly reducing costs.

Recent studies on experts using pocket-size imaging devices found them to be of clinical influence in 47% to 55% of patients, with a change of the primary diagnosis seen in up to 18% of patients.[11,12] The difference may be explained by small patient samples and the experience of the operators, in both clinical decision making and echocardiography. All of the medical residents were able to uncover findings of diagnostic use, and most (4 of 6) were able to change the initial diagnosis on the basis of their pocket-size ultrasound examinations. Ultrasound examinations are operator dependent, with proficiency increasing with increasing use.[20]

Table 4. Basic Characteristics, Pocket-size Imaging Findings, and Diagnoses in Patients With a Change of Primary Diagnosis

Baseline Information	Preliminary Diagnosis	Imaging Findings	New Diagnosis
Male, 66 y	Exertional dyspnea	Anterolateral hypokinesis	Previous MI
Male, 75 y, HTN, MI, AP, PVD, polio	COPD exacerbation	Reduced LV systolic function, dilated IVC with little respiratory variation	Congestive heart failure
Female, 77 y	Dizziness, presyncope	Preserved LV function, small IVC with inspiratory collapse	Dehydration
Male, 54 y, DM2, AF	Ascites, liver cirrhosis	DCM (dilated LV with reduced systolic function), ascites	DCM
Male, 98 y, DM2, MI, AP	GIH, anemia	Mass in right hypochondrium	Malignancy?
Male, 83 y, HTN, DM2, CVA	ACS	LVH with stiff LV, maintained radial systolic function, large TR, biatrial enlargement, dilated IVC with no respiratory variation	Diastolic congestive heart failure
Female, 85 y, AS	ACS	Thickened gallbladder wall with stone	Cholecystits, cholecystolithiasis
Female, 80 y, HTN, acute MI	Pleuritic chest pain, infection	Reduced systolic function, dilated IVC with reduced respiratory variation, small amount of left-sided pleural effusion	Congestive heart failure
Female, 83 y, HTN	Infection	HOCM, small IVC with large respiratory variation, liver metastasis	Liver metastasis, HOCM, dehydration
Female, 60 y, HTN, CVA, bipolar	CVA, presyncope	LVH, small IVC with large respiratory variation	Dehydration, LVH
Male, 82 y, HTN, cancer	Dyspnea, rapid AF	Reduced systolic function with apical ballooning pattern and basal hypercontractility	Takotsubo cardiomyopathy
Male, 66 y, AP, CVA	Hepatitis	Unknown pathologic structural process in liver	Thickened gallbladder, gallstone
Male, 83 y, HTN, DM2, COPD	COPD exacerbation	Reduced systolic function, moderate-severe AS, substantial amount of right-sided pleural effusion	Heart failure, AS

ACS indicates acute coronary syndrome; AF, atrial fibrillation; AP, angina pectoris; AS, aortic stenosis; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DCM, dilated cardiomyopathy; DM2, diabetes mellitus type 2; GIH, gastrointestinal hemorrhage; HOCM, hypertrophic obstructive cardiomyopathy; HTN, hypertension; IVC, inferior vena cava; LVH, left ventricular hypertrophy; MI, myocardial infarction; PVD, peripheral vascular disease; and TR, tricuspid regurgitation.

Similarly, the feasibility and correlation of pocket-size ultrasound versus reference methods were somewhat lower in the hands of nonexperts compared to experts, especially with regard to assessing abdominal structures.[8,11] This finding may reflect a population that is nonfasting and often in some form of acute distress, which renders the examination more difficult, especially in the hands of less-experienced operators. The reference method examinations, on the other hand, were done in a more timely fashion, under optimal conditions, and in the case of abdominal ultrasound, on fasting individuals. Despite these obstacles, abdominal examinations provided valuable clinical information.

In line with recent studies, age and cardiovascular risk were predictors of diagnostic use, probably reflecting an increased prevalence of disease in these groups.[11,12] The fact that many patients (30%–50%) with a change or verification of the diagnosis had an additional important diagnosis revealed by pocket-size ultrasound supports this hypothesis. Nevertheless, cardiovascular risk did not significantly predict diagnostic influence when corrected for age. Although twice as many patients older than 60 years had some diagnostic influence from pocket-size ultrasound, it still had significant diagnostic influence in one-fifth of patients younger than 60 years. Thus, we see the beneficial diagnostic influence of short routine goal-directed pocket-size ultrasound examinations in all age groups.

Physical examination is a cornerstone of clinical medicine and can in some cases be impressively accurate when performed by experienced clinicians,[21,22] but for other specific conditions, such as diagnosis of pericardial effusion, an abdominal aortic aneurysm, and aortic insufficiency, it falls short of echocardiography and ultrasound imaging.[23–26] Unfortunately, these finely honed clinical skills are diminishing among our colleagues as the face of modern medical practice is changing, resulting in an ever-increasing gap in the clinical skills between experienced and inexperienced clinicians.[1–3,27] The use of portable ultrasound devices as an adjunct to physical examination has been shown to bridge this gap in accuracy.[14,28,29] In this study, pocket-size ultrasound as an adjunct to physical examination influenced the diagnostics in 35% of patients. In addition, point-of-care ultrasound may be an effective learning tool for students and physicians in training.[30–35]

It is important to emphasize that pocket-size ultrasound should replace neither standard echocardiography or ultrasound imaging nor the standard physical examination. Rather it should be seen as a valuable adjunct to both, rapidly improving diagnostic precision and aiding in the selection of the patients most likely to benefit from formal echocardiography or other imaging modalities.[8,11–14,16,36,37] Users of pocket-size imaging devices should undergo a dedicated training program, as the diagnostic influence of ultrasound examinations is related to the skill of the user.[38]

Table 5. Predictors of the Diagnostic Influence of Bedside Pocket-size Ultrasound

Predictor of Any Use[a]	OR	95% CI	*P*
Age per 10 years[b]	1.39	(1.03–1.88)	.001
Any increased cardiovascular risk[b]	1.82	(0.99–3.3)	.05
Age per 10 years[c]	1.37	(1.11–1.67)	.004
Any increased cardiovascular risk[d]	1.20	(0.62–2.32)	.60

CI indicates confidence interval; and OR, odds ratio.
[a]Any use defined as a change or verification of the primary diagnosis or an additional important diagnosis.
[b]Not adjusted for age or cardiovascular risk.
[c]Adjusted for cardiovascular risk.
[d]Adjusted for age.

Limitations

Of the 446 patients randomized to pocket-size ultrasound examinations, only 199 were actually examined. This result can mainly be explained by busy working hours, in-hospital logistics, and resident instruction to prioritize standard diagnostics. Although patients allocated to undergo pocket-size ultrasound examinations were not necessarily examined consecutively, the selection bias was seemingly minimal, with the exception of patients with known malignancy, who were substantially overrepresented in the control groups. Such patients are more likely to be admitted for palliation, which may explain this finding.

The study was a single-center study with a limited number of participating residents and patients. Due to internal logistics, half of the 12 residents were randomized by draw to perform the pocket-size ultrasound examinations, instead of the more optimal randomization of patients. Analyses were performed as treated and not as intent to treat. Critical diagnoses such as aortic dissection and cardiac tamponade were not registered among the participants. How the results can be generalized to the use of an even simpler pocket-size imaging device is unknown.

Conclusions

By adding point-of-care pocket-size ultrasound examinations of approximately 11 minutes to the usual care, medical residents with limited ultrasound training were able to quickly change or verify the primary diagnosis in more than 1 of 6 patients (17%) and reveal an additional diagnosis that was important for treatment or follow-up in 1 of 4 patients (24%). In total, bedside examinations with the pocket-size imaging device importantly influenced the diagnosis in 1 of 3 patients (35%). Thus, even in the hands of nonexperts, routine use of a pocket-size imaging device as an adjunct to physical examination has the ability to improve in-hospital diagnostics and work flow.

References

1. Mangione S, Nieman LZ. Cardiac auscultatory skills of internal medicine and family practice trainees: a comparison of diagnostic proficiency. *JAMA* 1997; 278:717–722.
2. Vukanovic-Criley JM, Criley S, Warde CM, et al. Competency in cardiac examination skills in medical students, trainees, physicians, and faculty: a multicenter study. *Arch Intern Med* 2006; 166:610–616.
3. Wray NP, Friedland JA. Detection and correction of house staff error in physical diagnosis. *JAMA* 1983; 249:1035–1037.
4. Burton JL, Underwood J. Clinical, educational, and epidemiological value of autopsy. *Lancet* 2007; 369:1471–1480.
5. Kirch W, Schafii C. Misdiagnosis at a university hospital in 4 medical eras. *Medicine (Baltimore)* 1996; 75:29–40.
6. Combes A, Mokhtari M, Couvelard A, et al. Clinical and autopsy diagnoses in the intensive care unit: a prospective study. *Arch Intern Med* 2004; 164:389–392.
7. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med* 2011; 364:749–757.
8. Andersen GN, Haugen BO, Graven T, Salvesen Ø, Mjølstad OC, Dalen H. Feasibility and reliability of point-of-care pocket-sized echocardiography. *Eur J Echocardiogr* 2011; 12:665–670.
9. Testuz A, Müller H, Keller PF, et al. Diagnostic accuracy of pocket-size handheld echocardiographs used by cardiologists in the acute care setting. *Eur Heart J Cardiovasc Imaging* 2013; 14:38–42.
10. Prinz C, Voigt JU. Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography. *J Am Soc Echocardiogr* 2011; 24:111–116.
11. Mjølstad OC, Dalen H, Graven T, Kleinau JO, Salvesen O, Haugen BO. Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department. *Eur J Intern Med* 2012; 23:185–191.
12. Skjetne K, Graven T, Haugen BO, Salvesen Ø, Kleinau JO, Dalen H. Diagnostic influence of cardiovascular screening by pocket-size ultrasound in a cardiac unit. *Eur J Echocardiogr* 2011; 12:737–743.
13. Cardim N, Fernandez Golfin C, Ferreira D, et al. Usefulness of a new miniaturized echocardiographic system in outpatient cardiology consultations as an extension of physical examination. *J Am Soc Echocardiogr* 2011; 24:117–124.
14. Galderisi M, Santoro A, Versiero M, et al. Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples Ultrasound Stethoscope in Cardiology) study. *Cardiovasc Ultrasound* 2010; 8:51.
15. Frederiksen CA, Juhl-Olsen P, Larsen UT, Nielsen DG, Eika B, Sloth E. New pocket echocardiography device is interchangeable with high-end portable system when performed by experienced examiners. *Acta Anaesthesiol Scand* 2010; 54:1217–1223.
16. Badano LP, Nucifora G, Stacul S, et al. Improved workflow, sonographer productivity, and cost-effectiveness of echocardiographic service for inpatients by using miniaturized systems. *Eur J Echocardiogr* 2009; 10:537–542.
17. Vignon P, Chastagner C, Berkane V, et al. Quantitative assessment of pleural effusion in critically ill patients by means of ultrasonography. *Crit Care Med* 2005; 33:1757–1763.
18. Mjølstad OC, Andersen GN, Dalen H, et al. Feasibility and reliability of point-of-care pocket-size echocardiography performed by medical residents. *Eur Heart J Cardiovasc Imaging* 2013; 14:1195–1202.
19. Martin LD, Howell EE, Ziegelstein RC, et al. Hand-carried ultrasound performed by hospitalists: does it improve the cardiac physical examination? *Am J Med* 2009; 122:35–41.
20. Cawthorn TR, Nickel C, O'Reilly M, et al. Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students. *J Am Soc Echocardiogr* 2014; 27:302–309.
21. Lembo NJ, Dell'Italia LJ, Crawford MH, O'Rourke RA. Bedside diagnosis of systolic murmurs. *N Engl J Med* 1988; 318:1572–1578.
22. Pestana C, Weidman WH, Swan HJ, McGoon DC. Accuracy of preoperative diagnosis in congenital heart disease. *Am Heart J* 1966; 72:446–450.
23. Berger M, Bobak L, Jelveh M, Goldberg E. Pericardial effusion diagnosed by echocardiography: clinical and electrocardiographic findings in 171 patients. *Chest* 1978; 74:174–179.
24. Riba AL, Morganroth J. Unsuspected substantial pericardial effusions detected by echocardiography. *JAMA* 1976; 236:2623–2625.
25. Grayburn PA, Smith MD, Handshoe R, Friedman BJ, DeMaria AN. Detection of aortic insufficiency by standard echocardiography, pulsed Doppler echocardiography, and auscultation: a comparison of accuracies. *Ann Intern Med* 1986; 104:599–605.
26. Lederle FA, Walker JM, Reinke DB. Selective screening for abdominal aortic aneurysms with physical examination and ultrasound. *Arch Intern Med* 1988; 148:1753–1756.
27. Fitzgerald FT. Physical diagnosis versus modern technology: a review. *West J Med* 1990; 152:377–382.
28. Mouratev G, Howe D, Hoppmann R, et al. Teaching medical students ultrasound to measure liver size: comparison with experienced clinicians using physical examination alone. *Teach Learn Med* 2013; 25:84–88.
29. Kobal SL, Trento L, Baharami S, et al. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol* 2005; 96:1002–1006.
30. Hoppmann RA, Rao VV, Poston MB, et al. An integrated ultrasound curriculum (iUSC) for medical students: 4-year experience. *Crit Ultrasound J* 2011; 3:1–12.
31. Mircea PA, Badea R, Fodor D, Buzoianu AD. Using ultrasonography as a teaching support tool in undergraduate medical education: time to reach a decision. *Med Ultrason* 2012; 14:211–216.

32. Shapiro RS, Ko PP, Jacobson SN. A pilot project to study the use of ultrasonography for teaching physical examination to medical students. *Comput Biol Med* 2002; 32:403–409.
33. Barloon TJ, Brown BP, Abu-Yousef MM, et al. Teaching physical examination of the adult liver with use of real-time sonography. *Acad Radiol* 1998; 5:101–103.
34. Panoulas VF, Daigeler AL, Malaweera AS, et al. Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. *Eur Heart J Cardiovasc Imaging* 2013; 14:323–330.
35. Dalen H, Haugen BO, Graven T. Feasibility and clinical implementation of hand-held echocardiography. *Expert Rev Cardiovasc Ther* 2013; 11:49–54.
36. Mjølstad OC, Snare SR, Folkvord L, et al. Assessment of left ventricular function by GPs using pocket-sized ultrasound. *Fam Pract* 2012; 29:534–540.
37. Réant P, Dijos M, Arsac F, et al. Validation of a new bedside echoscopic heart examination resulting in an improvement in echo-lab workflow. *Arch Cardiovasc Dis* 2011; 104:171–177.
38. Sicari R, Galderisi M, Voigt JU, et al. The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography. *Eur J Echocardiogr* 2011; 12:85–87.

Paper 4

Andersen et al. BMC Medical Education 2014, 14:156
http://www.biomedcentral.com/1472-6920/14/156

BMC Medical Education

RESEARCH ARTICLE Open Access

Feasibility and accuracy of point-of-care pocket-size ultrasonography performed by medical students

Garrett Newton Andersen[1,3*], Annja Viset[4], Ole Christian Mjølstad[1,2], Øyvind Salvesen[5], Håvard Dalen[1,3] and Bjørn Olav Haugen[1,2]

Abstract

Background: Point-of-care ultrasound performed by clinicians is a useful supplement in the treatment and assessment of patients. We aimed to investigate whether medical students with minimal training were able to successfully acquire and interpret ultrasound images using a pocket-size imaging device (PSID) as a supplement to their clinical practice.

Methods: Thirty 5th year (of six) medical students volunteered to participate. They were each given a personal PSID device to use as a supplement to their physical examination during their allocated hospital terms. Prior to clinical placement the students were given three evenings of hands-on training with PSID by a board certified radiologist/cardiologist, including three short lectures (<20 min). The students were shown basic ultrasound techniques and taught to assess for basic, clinically relevant pathology. They were specifically instructed to assess for the presence or absence of reduced left ventricular function (assessed as mitral annular excursion < 10 mm), pericardial effusion, pleural effusion, lung comets, hydronephrosis, bladder distension, gallstones, abdominal free-fluid, cholecystitis, and estimate the diameter of abdominal aorta and inferior vena cava.

Results: A total of 211 patients were examined creating 1151 ultrasound recordings. Acceptable organ presentation was 73.8% (95% CI 63.1-82.6) for cardiovascular and 88.4% (95% CI: 80.6-93.6) for radiological structures. Diagnostic accuracy was 93.5% (95% CI: 89.0-96.2) and 93.2% (95% CI: 87.4-96.5) respectively.

Conclusion: Medical students with minimal training were able to use PSID as a supplement to standard physical examination and successfully acquire acceptable relevant organ recordings for presentation and correctly interpret these with great accuracy.

Keywords: Echocardiography, Point-of-care ultrasound, Bedside, Medical student, Hand-held

Background

We are increasingly reliant upon expensive and time-consuming biochemical and radiologic diagnostics to aid us in our evaluation of patients. Unfortunately this still results in major diagnostic errors in up to 30% of patients at autopsy [1-3]. Furthermore the increasing age and chronicity of the western population highlights the need for improved out of hospital diagnosis and treatment.

Point-of-care ultrasonography allows for the near instantaneous acquisition of real-time dynamic images, which can be correlated directly to the patient's signs and symptoms [4,5]. It has been shown to increase diagnostic accuracy, rapidly and cost effectively in the hands of experts and non-experts [6-13]. Furthermore, portable ultrasonography is a valuable teaching tool in medical anatomy and physiology as well as physical examination [14-18]. Despite this most medical students are not routinely educated in the clinical use of point-of-care ultrasonography, as they are in more widely accepted and traditional techniques, such as the stethoscope. This may in part be due to the lack of

* Correspondence: garrett.andersen@gmail.com
[1]MI Lab and Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Postboks 8905, 7491 Trondheim, Norway
[3]Levanger Hospital, Nord-Trøndelag Health Trust, 7600 Levanger, Norway
Full list of author information is available at the end of the article

evidence regarding the bedside use of pocket-size ultrasound by medical students.

We aimed to investigate whether medical students with minimal training were able to successfully acquire and interpret ultrasound images using a pocket-size imaging device (PSID) as a supplement to their clinical practice.

Methods

Medical students

The fifth year (of six) medical students eligible to participate in the study based on planned hospital rotations received verbal and written information from the authors regarding the study. Participation in the study was not part of the students' curriculum and all participating students were volunteers. The first 30 students whom volunteered were included in the study. There were no further inclusion or exclusion criteria. The number of participating students was limited to the number of available PSID. The medical students had similar limited experience in ultrasound.

Study population

All patients over 18 years of age, encountered in-hospital and at outpatient clinics during the students' clinical placement periods were eligible for inclusion. The patients were included from a total of seven regional hospitals between January-May 2012. There were no exclusion criteria, and all participating patients provided informed consent.

Training and education of medical students

The medical students received three evenings (nine hours) of combined theoretical and practical training in the use and interpretation of ultrasound images. The theoretical training was given as short didactical lectures by relevant specialists (cardiologists and radiologists) and focused on basic ultrasound physiology, anatomy and examples of normal and pathological ultrasound images. Students were specifically trained to assess for pathology relevant in the immediate emergency care of patients. They were instructed to assess for reduced left ventricular (LV) function defined as mitral annular excursion (MAE) < 10 mm [19-21], pericardial effusion, pleural effusion, lung comets, inferior vena cava (IVC) diameter and variation, hydronephrosis, bladder distension, gallstones, signs of cholecystitis, diameter of abdominal aorta (AA) and abdominal free-fluid. Practical hands-on training was given by relevant specialists and senior registrars, with students using their personal PSID. Students were encouraged to perform at least 75 examinations prior to placement.

Written informed consent was obtained from all patients. The Regional Committee for Medical and Health Research Ethics had no objections to the study's conduction, which was conducted according to the Declaration of Helsinki.

Pocket-size ultrasound examination

The ultrasound examination was performed bedside with a PSID, Vscan (GE Vingmed Ultrasound, Horten, Norway). The device measures 135 × 73 × 28 mm and weighs 390 g, including the phased-arrayed probe. Two-dimensional grey scale and live colour Doppler imaging are offered. The image sector for echocardiographic imaging is 75°. The bandwidth ranges from 1.7 to 3.8 MHz and is automatically adjusted. Storage and looping of a cardiac cycle are possible without ECG signal and looping of other structures is predefined and limited to 2 seconds. The device has separate modes optimized for cardiac and abdominal examinations. All images and recordings were saved on the device's micro-SD card and later transferred to a computer by commercial software (Gateway; GE Vingmed Ultrasound).

The bedside (point-of-care) cardiovascular ultrasound examination was performed with patients in the left-lateral decubitus and/or supine position. Assessment of LV global function was done from the apical four-chamber view using MAE, where MAE < 10 mm was classified as decreased LV function. Pericardial effusions were classified as present or not. The AA and IVC were assessed from the subcostal position. The AA diameter was assessed proximally to the bifurcation and if exceeding 35 mm classified as an abdominal aortic aneurysm (AAA). IVC diameter was measured end-expiratory within two cm from the right atrium orifice. All measurements of dimensions were done on the PSID. With patients in a supine or upright position, the pleura was assessed from left and right thoracic dorsolateral views, and assessed for the presence of pleural effusions and comet tails.

Other abdominal structures and spaces were assessed from a supine position looking specifically for hydronephrosis, bladder distension, gallstones, and signs of cholecystitis, and abdominal free-fluid.

Accuracy

The students were required to hand-in a log of selected examinations including their own set diagnosis based upon PSID examination. The specialists, one board certified radiologist and 2 board certified cardiologists with special interest in ultrasonography and echocardiography, were asked to categorize the image acquisition of relevant organ as acceptable or unacceptable for clinical interpretation and then determine whether the set diagnosis of the acceptable images were correct or incorrect. The specialists were not blinded to the set diagnosis.

Statistics

Data not following a normal distribution were presented as median and (interquartile) range. For sufficiently large samples logistic mixed model with random intercepts for students was used to examine estimate proportions. Clopper-Pearson estimates were used for small sample analyses. Sensitivity and specificity, negative and positive predictive value calculations were performed using relevant specialists as “gold standard”.

All the statistical analyses were performed using SPSS for Windows/Mac (version 20.0, SPSS, Inc.) or R version 2.13.1.

Results

Thirty 5th year (of six) medical students volunteered to participate in the study. At the end of the study period and their clinical placement, 21 (70%) medical students had performed exams using PSID and recorded their results. A total of 211 patients were examined (43% male, 38% female and 18% unrecorded sex), creating 1151 ultrasound recordings. Each student examined a median of 9 (±8, range 1–27) patients, producing a median of 49 (±49, range 5–169) ultrasound recordings. Acceptable organ presentation (Figure 1) was estimated to 73.8% (95% CI 63.1-82.6) for cardiovascular (heart, lungs and IVC) and 88.4% (95% CI: 80.6-93.6) for radiological (AA, renal system, gallbladder and abdominal free fluid) structures. Specifically, students performed best when acquiring images of the lungs and renal system (>93% (95% CI: 84.3-98.2) and found it most difficult to acquire acceptable images of the heart (71.2% (95% CI: 58.7-81.5)) and free fluid (73.2% (95% CI: 41.4-92.7)). The other categories (AA, IVC and gallbladder) had acceptable presentation in >80% (95% CI: 65.2-92.9) of cases. Diagnostic accuracy (Figure 2) was estimated at 93.5% (95% CI: 89.0-96.2) for cardiovascular structures and 93.2% (95% CI: 87.4-96.5) for radiological structures. The specific diagnostic accuracy was on a whole excellent. Diagnostic accuracy was close to 100% for AA (98.6% (95% CI: 92.7-100)) and free abdominal fluid (100% (95% CI: 76.8-100)) and lowest for gallbladder at 87.6% (95% CI: 73.7-95.1). The remaining categories showed diagnostic accuracy > 93% (95% CI: 83.3-99).

The estimated values for sensitivity, specificity, negative and positive predictive values of PSID are presented in Table 1.

Discussion

Medical students, with a limited amount of training, successfully incorporated the use of point-of-care ultrasonography in their clinical placements. They were able to correctly acquire bedside ultrasound images of cardiovascular and radiological structures in 74 and 88% of their patients and correctly interpret these images in 93% of cases.

An attempt to simulate real life scenarios was done when determining the feasibility and accuracy. In our experience, when non-experts use pocket-size ultrasound at the patients point-of-care they may have the need to clarify or present their ultrasound findings to a specialist for review or guidance. The specialists were in this setting used as the gold standard with regards to statistical analysis and were not blinded to the set diagnosis. Optimally this would have been done by higher order, formal imaging, but that was beyond the scope of this study in terms of logistics and economy.

Other studies have shown that medical students are able to quickly acquire ultrasound recordings of good quality on normal test subjects, in optimal conditions with a standard ultrasound machine and PSID after a brief period of training [22,23]. For the assessment of diagnostic accuracy in our study, only acceptable organ images were used. This may have diluted the true diagnostic accuracy to some extent. However the lack of a formal gold standard/reference made the basis for this, as assessing accuracy in non-acceptable images is useless when no reference is available.

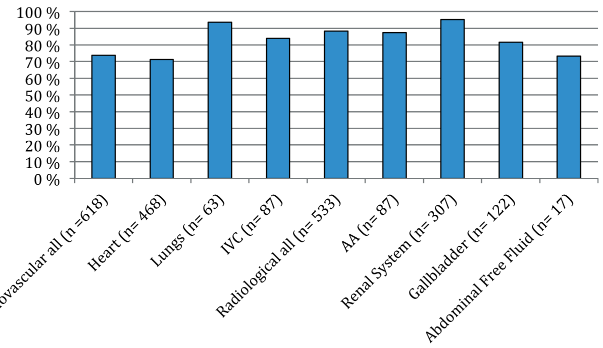


Figure 1 Acceptable organ presentation. Cardiovascular all; heart, IVC and Lungs, IVC; Inferior vena cava, Radiological all; includes AA, Renal system, Gallbladder and Abdominal free fluid. AA; Abdominal aorta.

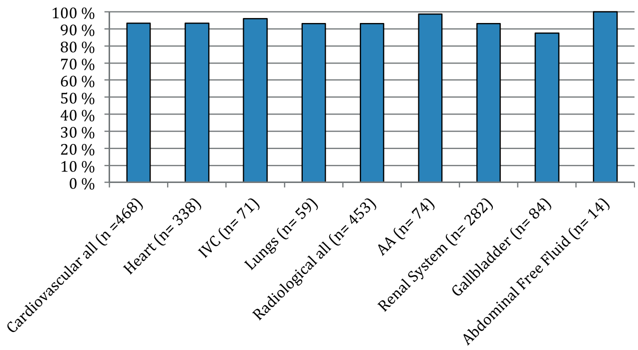


Figure 2 Correct diagnosis. Cardiovascular all; heart, IVC and Lungs, IVC; Inferior vena cava, Radiological all; includes AA, Renal system, Gallbladder and Abdominal free fluid. AA; Abdominal ao.

A recent, though smaller study with five final year medical students has shown encouraging results using pocket-size cardiac ultrasonography as an adjunct to standard physical examination in cardiology patients [9]. We have broadened the field, looking at several different organ systems and included diverse groups of hospital and emergency room patients.

The European Association of Echocardiography published a position statement in 2010 regarding with the use of PSID [24]. It supports the use of PSID as a teaching tool in medical schools, as a tool for a fast initial screening in the emergency setting, and as a complement to the standard physical examination.

Previous studies have shown increased accuracy, efficacy and diagnostic impact of pocket-size point-of-care ultrasonography in the hands of experts versus non-experts [6-8,11,13,25]. Thus the benefits of bedside PSID exams increase with increasing proficiency in its use and proficiency has been shown to increase with increasing use [23]. Additionally, ultrasonography has been shown to increase the skills of medical students in core subjects such as anatomy, physiology, and physical examination [9,14-18]. Therefore standardized training with an appropriate education program in the routine use PSID as an adjunct to standard physical examination should start as early as possible in a physician's career.

Limitations

The main limitation of this study is the inability to exclude for selection bias. With the use of their logbooks, students were able to select which ultrasound loops were eligible for review. This selection and spectrum bias may have lead to some overestimation of the results for feasibility and accuracy, however the degree of selection bias is in line with similar studies involving unselected residents and nurses [26,27]. Furthermore one student did not hand in a completed logbook and a further eight students did not perform any examinations with PSID and were therefore excluded from the study. The number of students not performing any examinations was probably influenced by several factors. Firstly the use of PSID in their clinical placement was not a mandatory exercise for the medical students. Secondly, as this was a trial of the use of PSID the students received specific

Table 1 Sensitivity, specificity, positive and negative predictive values

Pathology to detect	N Pathology (N total)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)
All cardiovascular	156 (468)	95.5 (90.9-97.9)	92.4 (83.7-96.9)	87.0 (75.3-93.4)	97.6 (95.0-98.8)
Cardiac only	115 (338)	98.3 (93.9-100) *	90.8 (78.8-96.7)	84.5 (62.6-95.6)	99.0 (96.4-99.9) *
IVC	20 (71)	84.5 (57.2-96.3)	100 (93.0-100) *	100 (80.5-100)*	94.8 (82.9-98.7)
Lungs	21 (59)	90.5 (68.8-97.6)	94.7 (82.2-99.4)*	90.5 (69.6-98.6) *	94.7 (82.2-99.2)*
All abdominal	104 (453)	92.6 (83–97.1)	92.2 (82.9-96.9)	80.1 (63.3-91.0)	97.5 (92.6-99.2)
AA	12 (74)	91.7 (61.5-98.6)*	100 (94.2-100)*	100 (71.3-100)*	98.4 (91.5-99.6)*
Renal system	48 (282)	89.9 (77.2-95.9)	93.3 (82.5-98.0)	73.1 (48.4-89.6)	97.5 (85.7-99.7)
Gallbladder	35 (84)	94.3 (80.8-99.1)*	85.6 (71.5-93.4)	82.4 (63.7-93.1)	95.5 (84.5-99.3*
Abdominal free fluid	9 (14)	100 (66.2-100)*	100 (48.0-100)*	100 (66.2-100)*	100 (48.0-100)*

N; number, *CI*; confidence interval, *PPV* positive predictive value, *NPV*; negative predictive value, *IVC*; inferior vena cava, *AA*; abdominal Aorta. * Clopper-Pearson CI.

instructions not to let the trial come in the way of their other academic responsibilities. Thirdly, the inclusion of patients was performed by the medical students themselves, which may have created a further barrier for its use. Lastly the use of ultrasound imaging is operator dependant, enthusiastic students will likely acquire more and better images reflecting a more realistic picture of it's clinical use, i.e. those skilled in ultrasound will also be the ones using it the most.

Conclusion

Medical students with minimal training were able to use PSID as a supplement to standard physical examination and successfully acquire acceptable relevant organ images for presentation and correctly interpret these with great accuracy. Incorporating training of point-of-care ultrasound in medical student education may be one step further towards a more widespread use of ultrasound and a faster and more accurate diagnosis for patients.

Abbreviations

PSID: Pocket-size imaging device; LV: Left ventricular; MAE: Mitral annular excursion; IVC: Inferior vena cava; AA: Abdominal aorta; AAA: Abdominal aortic aneurysm.

Competing interests

GE Healthcare provided 20 of the 30 PSID devices used during this study as a loan. No financial support was received.

Authors' contributions

GNA participated in the study design and coordination, education of medical students, data processing, performed the statistical analysis and drafted the manuscript. AV participated in the coordination of the study, education of the medical students and review of relevant images. OCM participated in the coordination of the study, education of the medical students and review of relevant images. ØS participated in the design of the study and performed the statistical analysis. HD participated in the design of the study, performed the statistical analysis and helped to draft the manuscript. BOH conceived of the study and participated in its design and coordination, education of the medical students and review of relevant images and helped to draft the manuscript. All authors read and approved the final manuscript.

Acknowledgements

We thank all the participating medical students for their invaluable assistance with the inclusion and data collection for this study. The Norwegian University of Science and Technology (NTNU) and Nord-Trøndelag Health Trust, both Norway, funded this study. GNA, OCM, HD and BOH hold positions at the Medical Imaging Laboratory, NTNU, a Centre of Research-based Innovation that is funded by the Research Council of Norway and industry. One of the industry partners is GE Vingmed Ultrasound. The Centre has a total budget of app. 124 million NOK for the 8 year period 2007–2014, and the contribution from GE Vingmed Ultrasound to this budget is app. 7 million NOK (app. 6%).

Author details

[1]MI Lab and Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Postboks 8905, 7491 Trondheim, Norway. [2]Clinic of Cardiology, St. Olav Trondheim University Hospital, Trondheim, Norway. [3]Levanger Hospital, Nord-Trøndelag Health Trust, 7600 Levanger, Norway. [4]Clinic of Radiology and Nuclear Medicine, St. Olav Trondheim University Hospital, Trondheim, Norway. [5]Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, Trondheim, Norway.

Received: 4 January 2014 Accepted: 17 July 2014
Published: 28 July 2014

References

1. Burton JL, Underwood J: **Clinical, educational, and epidemiological value of autopsy.** *Lancet* 2007, **369**(9571):1471–1480.
2. Kirch W, Schafii C: **Misdiagnosis at a university hospital in 4 medical eras.** *Medicine (Baltimore)* 1996, **75**(1):29–40.
3. Pastores SM, Dulu A, Voigt L, Raoof N, Alicea M, Halpern NA: **Premortem clinical diagnoses and postmortem autopsy findings: discrepancies in critically ill cancer patients.** *Crit Care* 2007, **11**(2):R48.
4. Moore CL, Copel JA: **Point-of-care ultrasonography.** *N Engl J Med* 2011, **364**(8):749–757.
5. Kimura BJ, Amundson SA, Shaw DJ: **Hospitalist use of hand-carried ultrasound: preparing for battle.** *J Hosp Med* 2010, **5**(3):163–167.
6. Andersen GN, Haugen BO, Graven T, Salvesen Ø, Mjølstad OC, Dalen H: **Feasibility and reliability of point-of-care pocket-sized echocardiography.** *Eur J Echocardiogr* 2011, **12**(9):665–670.
7. Galderisi M, Santoro A, Versiero M, Lomoriello VS, Esposito R, Raia R, Farina F, Schiattarella PL, Bonito M, Olibet M, de Simone G: **Improved cardiovascular diagnostic accuracy by pocket size imaging device in non-cardiologic outpatients: the NaUSiCa (Naples ultrasound stethoscope in cardiology) study.** *Cardiovasc Ultrasound* 2010, **8**:51.
8. Mjølstad OC, Dalen H, Graven T, Kleinau JO, Salvesen O, Haugen BO: **Routinely adding ultrasound examinations by pocket-sized ultrasound devices improves inpatient diagnostics in a medical department.** *Eur J Intern Med* 2012, **23**(2):185–191.
9. Panoulas VF, Daigeler AL, Malaweera AS, Lota AS, Baskaran D, Rahman S, Nihoyannopoulos P: **Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors.** *Eur Heart J Cardiovasc Imaging* 2013, **14**(4):323–330.
10. Prinz C, Voigt J-U: **Diagnostic accuracy of a hand-held ultrasound scanner in routine patients referred for echocardiography.** *J Am Soc Echocardiogr* 2011, **24**(2):111–116.
11. Skjetne K, Graven T, Haugen BO, Salvesen Ø, Kleinau JO, Dalen H: **Diagnostic influence of cardiovascular screening by pocket-size ultrasound in a cardiac unit.** *Eur J Echocardiogr* 2011, **12**(10):737–743.
12. Badano LP, Nucifora G, Stacul S, Gianfagna P, Pericoli M, Del Mestre L, Buiese S, Compassi R, Tonutti G, Di Benedetto L, Fioretti PM: **Improved workflow, sonographer productivity, and cost-effectiveness of echocardiographic service for inpatients by using miniaturized systems.** *Eur J Echocardiogr* 2009, **10**(4):537–542.
13. Mjolstad OC, Andersen GN, Dalen H, Graven T, Skjetne K, Kleinau JO, Haugen BO: **Feasibility and reliability of point-of-care pocket-size echocardiography performed by medical residents.** *Eur Heart J Cardiovasc Imaging* 2013, **14**(12):1195–1202.
14. Mircea P-A, Badea R, Fodor D, Buzoianu AD: **Using ultrasonography as a teaching support tool in undergraduate medical education – time to reach a decision.** *Med Ultrason* 2012, **14**(3):211–216.
15. Mouratev G, Howe D, Hoppmann R, Poston MB, Reid R, Varnadoe J, Smith S, McCallum B, Rao V, Demarco P: **Teaching medical students ultrasound to measure liver size: comparison with experienced clinicians using physical examination alone.** *Teach Learn Med* 2013, **25**(1):84–88.
16. Decara JM, Kirkpatrick JN, Spencer KT, Ward RP, Kasza K, Furlong K, Lang RM: **Use of hand-carried ultrasound devices to augment the accuracy of medical student bedside cardiac diagnoses.** *J Am Soc Echocardiogr* 2005, **18**(3):257–263.
17. Swamy M, Searle RF: **Anatomy teaching with portable ultrasound to medical students.** *BMC Med Educ* 2012, **12**:99.
18. Sweetman GM, Crawford G, Hird K, Fear MW: **The benefits and limitations of using ultrasonography to supplement anatomical understanding.** *Anat Sci Educ* 2013, **6**(3):141–148.
19. Alam M, Hoglund C, Thorstrand C: **Longitudinal systolic shortening of the left ventricle: an echocardiographic study in subjects with and without preserved global function.** *Clin Physiol* 1992, **12**(4):443–452.
20. Hoglund C, Alam M, Thorstrand C: **Atrioventricular valve plane displacement in healthy persons. An echocardiographic study.** *Acta Med Scand* 1988, **224**(6):557–562.
21. Alam M, Hoglund C, Thorstrand C, Philip A: **Atrioventricular plane displacement in severe congestive heart failure following dilated cardiomyopathy or myocardial infarction.** *J Intern Med* 1990, **228**(6):569–575.
22. Fernandez-Frackelton M, Peterson M, Lewis RJ, Perez JE, Coates WC: **A bedside ultrasound curriculum for medical students: prospective evaluation of skill acquisition.** *Teach Learn Med* 2007, **19**(1):14–19.

23. Cawthorn TR, Nickel C, O'Reilly M, Kafka H, Tam JW, Jackson LC, Sanfilippo AJ, Johri AM: **Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students.** *J Am Soc Echocardiogr* 2014, **27**(3):302–309.
24. Sicari R, Galderisi M, Voigt JU, Habib G, Zamorano JL, Lancellotti P, Badano LP: **The use of pocket-size imaging devices: a position statement of the European Association of Echocardiography.** *Eur J Echocardiogr* 2011, **12**(2):85–87.
25. Frederiksen CA, Juhl-Olsen P, Larsen UT, Nielsen DG, Eika B, Sloth E: **New pocket echocardiography device is interchangeable with high-end portable system when performed by experienced examiners.** *Acta Anaesthesiol Scand* 2010, **54**(10):1217–1223.
26. Ruddox V, Stokke TM, Edvardsen T, Hjelmesaeth J, Aune E, Baekkevar M, Norum IB, Otterstad JE: **The diagnostic accuracy of pocket-size cardiac ultrasound performed by unselected residents with minimal training.** *Int J Cardiovasc Imaging* 2013, **29**(8):1749–1757.
27. Henderson SO, Ahern T, Williams D, Mailhot T, Mandavia D: **Emergency department ultrasound by nurse practitioners.** *J Am Acad Nurse Pract* 2010, **22**(7):352–355.

doi:10.1186/1472-6920-14-156
Cite this article as: Andersen *et al.*: Feasibility and accuracy of point-of-care pocket-size ultrasonography performed by medical students. *BMC Medical Education* 2014 **14**:156.