Feasibility and Accuracy of Tele-Echocardiography, With Examinations by Nurses and Interpretation by an Expert via Telemedicine, in an Outpatient Heart Failure Clinic

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Objectives—To study the feasibility and accuracy of focused echocardiography by nurses supported by near–real-time interpretation via telemedicine by an experienced cardiologist.

Methods—Fifty consecutive patients were included from an outpatient heart failure (HF) clinic. Limited echocardiography was performed by 1 of 3 specialized nurses. The echocardiograms were transferred by a secure transfer model for near–real-time interpretation to 1 out-of-hospital cardiologist, assessing, among others, the left ventricular (LV) internal diameter, end-diastolic volume, ejection fraction, left atrial (LA) indexed end-systolic volume, mitral early inflow velocity (E), the ratio of E to mitral late inflow, and the ratio of E to the mitral annular early diastolic velocity. The reference method was echocardiography by 1 of 4 experienced cardiologists.

Results—The median age of the population (46% women) was 79 (range, 33–95) years. The assessment and quantification of LA and LV dimensions, volumes, and functional indices were feasible in 94% or more via the telemedical approach. The agreement with reference measurements was very high by the telemedical approach. The mean duration of the complete telemedical approach from the start of echocardiography until the cardiologist’s report was received by the caregiving nurse was 1.32 ± 0.36 (range, 1.58) hours. The correlations with reference to the above-specified indices were $r = 0.75$ to 0.94.

Conclusions—Limited echocardiography by nurses in an outpatient heart failure clinic, supported by interpretation by an out-of-hospital cardiologist, was feasible and reliable. This may reduce geographic disparities and allow more patients to benefit from the advantages of implementing focused echocardiography by non-cardiologists in diagnostics and follow-up.

Key Words—echocardiography; heart failure; nonexpert; nurse; telemedicine

Modern technology allows for fast and safe transfer of patient information, which has not previously been attainable. Telecommunication technology (telemedicine) provides delivery of health services where distance is a critical factor. Today, access to the Internet and, thus, the potential
to use telemedicine is available in most places in the world through local area networks and wireless mobile telecommunication technology.

Heart failure (HF) is associated with a poor prognosis and a reduced quality of life, and the financial burden on the health care system is substantial. Despite current treatment options, HF morbidity and mortality are still high, and 25% to 50% of all patients with HF are readmitted within 6 months of hospitalization after decompensated HF. Guidelines advocate classification of HF by the left ventricular ejection fraction (LVEF), as this is decisive for both treatment and prognosis. Patients with HF who have an EF of 50% or higher are classified as having heart failure with a preserved ejection fraction (HFrEF). Similarly, patients with HF who have an EF of 40% to 49% and an EF of 40% or lower are classified as having heart failure with a midrange ejection fraction (HFmrEF) and heart failure with a reduced ejection fraction (HFpEF), respectively. Furthermore, the size and function of the cardiac chambers are easily depictable by echocardiography.

Fluid retention is the major consequence of decompensation, which usually happens over time with late-onset symptoms and an unpredictable course. Patients with HF could benefit from frequent volume status assessments and more aggressive therapy. The assessment of the volume status in patients with HF may be improved by evaluation of the presence of pleural effusion and the dimension and collapsibility of the inferior vena cava. The classification of the HF category, estimation of filling pressures, and estimation of the volume status can be performed by echocardiography.

Echocardiography is usually performed by specialized sonographers or experienced cardiologists. Interpretation of the recordings is usually performed at the same location as the examination. Implementation of telemedicine for interpretation of images at remote locations is common in the field of radiology to reduce the workload of local radiologists. The research regarding tele-echocardiography is scarce. The first studies on tele-echocardiography were conducted by pediatric cardiologists as support for physicians in rural areas. So far, telemedicine has not found its way into routine follow-up of patients with HF. However, tele-echocardiography allows for the performance of echocardiographic recordings at one location and interpretation by an expert at another; thus, patients can benefit from the positive impact of more precise diagnostics.

The aim of the study was to examine the feasibility and accuracy of tele-echocardiography in an outpatient HF clinic. We combined echocardiographic recordings by trained nurses with transfer of echocardiographic data by local area networks and wireless mobile telecommunication for interpretation by a cardiologist at a remote location. The purpose of the study was not to implement limited ultrasound in the routine follow-up of patients with HF, but the aim was to explore the benefit in HF follow-up where tele-echocardiography can overcome geographic challenges to improve HF diagnostics and care. Second, we aimed to evaluate the accuracy of tele-echocardiography for classification of HF and evaluation of filling pressures.

Materials and Methods

Study Population
Patients from an outpatient HF clinic were recruited at Levanger Hospital, Nord-Trøndelag Health Trust. All patients were followed for known HF and had previous echocardiographic examinations performed by a cardiologist. Only patients older than 18 years were eligible for inclusion between October 2016 and February 2017. All participants gave their informed written consent before inclusion. The study was conducted in conformity with the policy statement for the use of human subjects of the Declaration of Helsinki. The study was approved by the Regional Committee for Medical and Health Research Ethics (REK 2015/2312) and registered in the ClinicalTrials.gov database (NCT02936050).

Training and Education of Nurses
Three registered cardiac nurses with 6 to 12 years of clinical experience from a nurse-led outpatient HF clinic were trained in performing echocardiographic recordings by two cardiologists. The nurses had no previous experience in echocardiographic recordings or image analyses. However, they were familiar with the use of handheld ultrasound devices for evaluation of the size and respiratory variation of the inferior vena cava and assessment of pathologic fluid in the pericardium and pleural cavities to aid in their clinical work with patients with HF. Lung ultrasound was not included in the training. They underwent systematic training by cardiologists with experience in echocardiography and...
performed a mean of 67 (range, 47–97) lifetime examinations before patient inclusion. Initially, they performed approximately five echocardiographic examinations with hands-on training support.

**Tele-Echocardiography With Recordings by Nurses and Interpretation by Telemedicine**

A Vivid 7 scanner (GE Healthcare AS, Horten, Norway) was used by the nurses to obtain goal-directed echocardiographic recordings of the following standard views: parasternal long- and short-axis (with and without color Doppler), 3 standard apical views (4-chamber, 2-chamber, and long-axis) with and without color Doppler focusing on left ventricular (LV), left atrial (LA), and right ventricular subcostal views for assessment of the inferior vena cava, pulsed wave tissue Doppler imaging with a sample volume in the basal part of the septal and lateral walls (4-chamber), pulsed wave Doppler recordings of mitral inflow, and continuous wave Doppler imaging of the blood flow through the aortic valve and tricuspid regurgitations. All recordings contained at least 3 cardiac cycles. The recording of the inferior vena cava included both maximum and minimum dimensions by including a quick inspiration (sniff). Both pleural cavities were assessed in the midclavicular and midaxillary line in a sitting position with the transducer in the intercostal spaces, as described earlier, and in cases of pleural effusion, longitudinal and transverse images were recorded. The amount of fluid was quantified as the distance from the diaphragm to the basal part of the lung, annotated as 0 in cases of no pleural effusion. No ultrasound examinations of the lungs were included. The nurses had access to patient histories and key words of previous echocardiographic examinations, but importantly, they did not have access to previous echocardiographic recordings.

Transfer of the recordings was done immediately after the examination. A commercial software- and hardware-based system (PaCentric; Fimreite Software, Stavanger, Norway) was used. PaCentric allows for secure transmission, interpretation, and reporting of medical Digital Imaging and Communications in Medicine images per the Internet. The data were stored securely and depersonalized. PaCentric is accredited (International Organization for Standardization 13485:2003) and certified (Conformité Européenne 0434), as well as approved by the US Food and Drug Administration (510 k100837). Transmission of the recordings was allowed by installing the software on the Vivid 7 scanner connected to the hospital’s local area network. After the end of the examination, data were exported to the PaCentric server and stored on an ordinary, password-protected laptop computer by the cardiologist who performed all of the analyses. Both local area networks and mobile telecommunications network solutions were used, depending on the availability at the interpreter’s actual location.

The interpretation of the recordings by the out-of-hospital cardiologist was performed in EchoPAC SWO (version BT12; GE Healthcare). The out-of-hospital cardiologist was blinded to all previous echocardiographic recordings and patient histories. All measurements reflect the average of at least 3 cardiac cycles. The LV endocardial borders were traced in end diastole and end systole in 4- and 2-chamber views. The LV internal length was measured from the traces and LV volumes (end-diastolic and end-systolic), and the EF was calculated by biplanar Simpson method. The LV internal diameter and wall thickness were measured at the level of the tip of the mitral leaflets in 2-dimensional grayscale recordings. The LA endocardial border was traced in end systole in 4- and 2-chamber views, and the volume was calculated by the area-length method and subsequently indexed per square meter body surface area (left atrial volume index [LAVI]). The pulmonary veins and the LA appendage were not included in the trace. Mitral inflow peak early (E) and late (A) velocities and the early filling mitral deceleration time were measured in pulsed wave Doppler recordings from the apical 4-chamber view. The peak velocity of the tricuspid regurgitation was measured by continuous wave Doppler imaging. Mitral annular peak systolic (S') and peak early diastolic (e') longitudinal velocities were assessed by pulsed-wave tissue Doppler imaging. The ratio of the early mitral inflow to the early diastolic mitral annular velocity (E/e') was calculated. The LV filling pressure was estimated according to recommendations by the European Association of Cardiovascular Imaging and the American Society of Echocardiography, based on the LAVI, e', E/e', and peak velocity of the tricuspid regurgitation for the HF subgroups as normal or elevated.9
**Reference Echocardiography**

Reference echocardiography was performed immediately after the nurses’ recordings by 1 of 4 in-house physicians experienced in echocardiography (3 cardiologists and 1 experienced resident in cardiology). They were not blinded to medical histories or previous echocardiographic recordings from the patients. However, they were blinded to the echocardiographic examinations performed by the nurses and analyzed by the out-of-hospital cardiologist by telemedicine. The reference examinations were performed at the same department but in another room. High-end echocardiographic scanners (Vivid E9 and Vivid E95) were used. The reference imaging included the same recordings, and in addition, all other chambers and valves were assessed. The echocardiographic measurements were performed as indicated above.

**Patient Flow**

The patients were first examined by 1 of 3 registered cardiac nurses, who immediately transferred the echocardiographic data for further analyses by telemedicine. The recordings obtained by the nurses were interpreted in near real time via the tele-echocardiographic approach by an out-of-hospital cardiologist (Figure 1). No further follow-up or ultrasound examinations of the participants were performed during the study.

Before echocardiography, blood samples were drawn the same day and analyzed at the in-hospital accredited laboratory. Serum N-terminal pro-brain natriuretic peptide, serum creatinine, and estimated glomerular filtration rate (calculated by the Cockcroft-Gault equation) values were measured for characterization of

| Parameter                        | Value       |
|----------------------------------|-------------|
| Age, years                       | 77 ± 12 (62)|
| Women, n (%)                     | 23 (46)     |
| BMI, kg/m²                       | 25.5 ± 5.3 (28.3) |
| Systolic blood pressure, mm Hg   | 131 ± 22 (101) |
| Diastolic blood pressure, mm Hg  | 76 ± 11 (50)  |
| NT-Pro-BNP, ng/L                 | 4,320 ± 7,014 (44,867) |
| eGFR, mL/min/1.73m²              | 44 ± 26 (126)  |
| NYHA functional class            | 1.9 ± 0.7 (3)   |
| I (N)                            | 12          |
| II (N)                           | 25          |
| III (N)                          | 7           |
| IV (N)                           | 1           |
| Atrial fibrillation, n (%)       | 24 (48)     |
| Diuretics, n (%)                 | 42 (84)     |
| Beta-blocker, n (%)              | 40 (80)     |
| ACEI/ARB, n (%)                  | 18 (36)     |

Data are presented as mean ± SD (range) unless otherwise specified. ACEI/ARB indicates angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker; BMI, body mass index; eGFR, estimated glomerular filtration rate; NT-Pro-BNP, N-terminal pro-B-type natriuretic peptide; and NYHA, New York Heart Association. 

*Cockcroft-Gault equation.*

![Figure 1](image-url). Patient flow throughout the study. Patients with HF were examined by 1 of 3 specialist nurses and immediately after by 1 of 3 expert echocardiographers. The images acquired by the nurses were interpreted and analyzed by an out-of-hospital cardiologist via telemedicine.
the population. The New York Heart Association functional classification was scored by the nurses, and the body weight (kilograms), body height (centimeters), and blood pressure (millimeters of mercury) were measured. Anthropometric measurements were rounded up to the nearest multiple of 1.

Statistical Analyses

Descriptive statistics were used for describing the study population. Data are presented as mean ± SD, but data not following a normal distribution are presented as median (range). Categorical data are reported as numbers and percentages. The agreement of the measurements by the telemedical approach and reference was tested by Bland–Altman statistics, the coefficient of variation, and the Pearson or Spearman correlation coefficient. Proportions were analyzed by the χ² test. Agreement with respect to the correct HF classification was analyzed by the weighted κ statistic. Comparisons of means were tested by paired t tests or the related-sample Wilcoxon signed rank test. Two-sided P < .05 was considered statistically significant. Semiquantitative data were further assessed by calculations of sensitivity and specificity and negative and positive predictive values. The association of the type of HF with the correct classification of LV filling pressures was analyzed by logistic regression analyses.

Results

Population

Baseline data for the 50 participants are shown in Table 1. The mean age was 77 ± 12 years; 46% were women; and the mean body mass index was 25.6 ± 5.9 kg/m². The mean estimated glomerular
Figure 2. Bland–Altman plots illustrating the agreement between the telemedical approach and reference echocardiography for the LVEF (A), LAVI (B), E/e' ratio (C), and maximal tricuspid regurgitation pressure gradient (TR max P; D). The differences of the respective measurements are plotted against the means of the measurements.

Table 4. Agreement Between Echocardiographic Indices by the Telemedical Approach and Reference Cardiologist

| Parameter                                | n (Pairs) | Correlation (P) | CoV, % | Bias  |
|------------------------------------------|-----------|-----------------|--------|-------|
| LVEF                                     | 48        | 0.78 (.002)     | 11.7   | 1.0   |
| LV end-diastolic volume                  | 47        | 0.85 (<.001)    | 12.6   | −3.3  |
| LV internal end-diastolic diameter       | 49        | 0.80 (.01)      | 8.0    | −3.6  |
| LA end-systolic volume index             | 46        | 0.75 (.004)     | 14.8   | 0.7   |
| Mitral early diastolic velocity          | 48        | 0.94 (<.001)    | 10.2   | 1.3   |
| Mitral annular early diastolic velocity  | 48        | 0.82 (<.001)    | 12.8   | 0.3   |
| Mitral annular systolic velocity         | 48        | 0.80 (.001)     | 10.9   | −0.1  |
| Mitral E/A ratio                         | 21        | 0.88 (.001)     | 13.5   | 0.2   |
| E/e' ratio                               | 46        | 0.88 (<.001)    | 16.7   | −0.6  |
| Tricuspid regurgitation peak velocity    | 31        | 0.71 (.007)     | 8.4    | −0.2  |
| LV end-diastolic length                  | 48        | 0.74 (.004)     | 6.7    | 0.7   |
| LA end-systolic length                   | 49        | 0.72 (.006)     | 6.1    | 0.4   |
| IVS end-diastolic thickness              | 48        | 0.62 (.02)      | 13.2   | 0.7   |
| LV posterior wall end-diastolic thickness | 48       | 0.60 (.03)      | 15.0   | 1.00  |
| Pleural effusiona                        | 100       | 0.88 (<.001)    | 0.1    |       |

Bias was measured as telemedical approach mean values minus mean reference values. CoV indicates coefficient of variation; and IVS, interventricular septum.

*As described in Table 3.
filtration rate was 44 ± 29 mL/min. Diuretics, beta blockers, and angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers were used by 84%, 80%, and 36% of the population, respectively. The low proportion of patients treated with angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers was related to the high prevalence of renal failure in the population and the fact that optimal HF therapy was not yet achieved.

Feasibility of Tele-Echocardiography

Table 2 shows the time used for the telemedical approach. The mean duration of the examination by the nurses from the start of echocardiography until the reference imaging results were positive. Delays were primarily caused by computer crashes and long downloads, leading to inaccessibility of images within reasonable time.

At the time of data transmission, the computer of the out-of-hospital cardiologist was connected to the Internet by fiber-optic cables in 30 (60%) examinations, an asymmetric digital subscriber line in 9 (18%), and wireless mobile networks (3G and 4G) in 11 (22%). The mean duration of transfer varied by the mode of telecommunication, being shortest for fiber-optic cables (0.32 ± 0.25 [range, 0.07–1.27] hours), followed by the asymmetric digital subscriber line (0.35 ± 0.20 [range, 0.10–0.67] hours) and wireless mobile networks (0.48 ± 0.28 [range, 0.22–1.22] hours), respectively.

Comparison of the tele-echocardiographic data with the reference measurements is shown in Table 3. Feasibility was high for all indices, except for the mitral E/A ratio and peak velocity of the tricuspid regurgitation. Only the LV internal end-diastolic diameter, LV posterior wall end-diastolic thickness, and tricuspid regurgitation peak velocity were significantly different between the methods (P < .02). By tele-echocardiography, LV endocardial borders in end diastole were underestimated by 3 mm (49 versus 52 mm), and LV length was overestimated by 5 mm (84 versus 79 mm).

The agreements of measurements by telemedicine and the reference for the EF, LAVI, maximal tricuspid regurgitation gradient, and E'/e' ratio are illustrated in Figure 2 and Table 4. The biases for the different measurements were close to 0, and there was no significant relationship between the errors and the magnitudes of the measurements. Coefficients of variation for the above-mentioned central indices were all in the range of 6% to 15% (Table 4). The correlations were high for all echocardiographic indices (r ≥ 0.71; P ≤ .007), except for measurements of wall thickness, for which the correlations were moderate for both the interventricular septum and the posterior wall (both r ≥ 0.60; P ≤ .03). Pleural effusion was revealed in a total of 9 pleural cavities by either the reference or the telemedical approach. The latter detected pleural effusion in 7 of 8 cavities in which reference imaging results were positive.

Tele-echocardiography showed substantial agreement with the reference for classification of the category of HF, with a weighted κ of 0.73 (P < .001). Importantly, no participants were misclassified between mEF and pEF or rEF. The LV filling pressure was determined by the telemedical approach and reference in 39 and 41 of the 50 cases, respectively, and in 31 cases, the filling pressure was determined by both approaches (Figure 3). Among the misclassified cases, HFpEF and HFmrEF were numerically more prevalent, including all cases by the telemedical approach and 7 (71%) by reference.

Valvular disease was evaluated semiquantitatively. The sensitivity and specificity for tele-echocardiography to detect at least moderate mitral stenosis, mitral regurgitation, and tricuspid regurgitation were 100% and
95% or higher, respectively. For detection of at least moderate aortic stenosis (n = 8, but only 7 cases available for the analyses) the sensitivity was lower (43%) but still with excellent specificity (97%).

Discussion

We are currently unaware of other studies evaluating tele-echocardiography with recordings by nonphysician personnel at a single geographic location combined with near–real-time interpretation by a cardiologist at another. The telemedical approach was feasible and reliable in this HF population. The most important finding of this study is that by using expert support by telemedicine, more patients with HF can gain the benefit of diagnostic ultrasound. Such an approach may improve diagnostics and care when distance and available resources matter.

The limited echocardiographic approach presented here may be used during the initial evaluation of a patient with suspected HF, making information available. Thus, the time delay to diagnosis can be reduced by improving the basis for decisions on the right workup. Importantly, the aim was not to replace comprehensive echocardiography by this approach but to evaluate whether telemedicine could support clinical decision making when the echocardiographic recordings were in the hands of inexperienced users.

The time spent on the echocardiographic recordings by the nurses was, on average, 0.5 hour and within range of what is acceptable and feasible in the everyday clinical practice for a nurse-lead outpatient clinic. Similarly, the time spent for transfer, analyses, and reporting was short and allows for implementation. Even though the time used for transfer of the recordings depended on the local area network available, the approach was feasible for near–real-time interpretation, also when a 3G/4G mobile network was used. This was in line with previous studies. The out-of-hospital cardiologist’s categorization of the type of HF via the telemedical approach was comparable to the in-hospital cardiologist’s reference echocardiography. Thus, geographic challenges can be overcome with the use of telemedicine for support of dedicated health care personnel in remote areas where traveling is a burden.

The telemedical software used is approved and complies with the regulations set by the Norwegian Data Protection Authority. With this software, sensitive data can be transferred and directly imported into EchoPAC (GE Healthcare) software for analyses, which presents a great advantage in simplifying the work flow. Today, several vendors provide similar software for transfer of imaging data, in accordance with the European Union general data protection regulations.

The three nurses performing the recordings had undergone dedicated, but limited training. Their training exceeded the recommendations for focused cardiac ultrasound examinations but did not reach the level recommended for comprehensive echocardiography. In line with others, our results may add knowledge, and consequently, more patients can benefit from the diagnostic yield of echocardiography. As shown both in HF and other populations, diagnostic ultrasound may add important information, even when those performing the examinations have limited experience. In this study, all patients were additionally examined by a cardiologist, and the results indicate that echocardiographic recordings by nurses combined with interpretation by a cardiologist add important information to the clinical decision making. To evaluate the clinical benefit of this approach, larger clinical studies are warranted.

As shown by the semiquantitative assessment of valvular disease, more training of the users may be needed to safely exclude valvular disease. Other studies evaluating handheld ultrasound devices by inexperienced users have also shown that evaluating valvular disease may be challenging, and our group has previously shown that inexperienced users of diagnostic ultrasound perform better in assessments of global LV function than valvular assessments. However, a valvular assessment was not the purpose of this study; thus, the results presented are in line with what was expected. The results highlight the need for dedicated training in any given task for operators of diagnostic ultrasound.

The telemedical calculations of dimensions, volumes, and flow measurements were well in line with reference measurements. Most differences were non-significant. There were only small but significant differences for the LV internal end-diastolic diameter, end-diastolic length, and posterior wall end-diastolic thickness (mean differences of 3, 5, and 0.9 mm, respectively) for the aortic root. The telemedical software used is approved and complies with the regulations set by the Norwegian Data Protection Authority. With this software, sensitive data can be transferred and directly imported into EchoPAC (GE Healthcare) software for analyses, which presents a great advantage in simplifying the work flow. Today, several vendors provide similar software for transfer of imaging data, in accordance with the European Union general data protection regulations.

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lyses. The prevalence of HFpEF in the study popu-
from HFmrEF to HFrEF or HFpEF in repeated ana-
Furtheremore, on the basis of the published repeatabil-
EF can correctly classify HF into different categories.
The recently introduced new HF class HFmrEF has cau-
sed intense debate, as it is based on the idea that the
related to HFmrEF versus HFrEF or HFpEF. The
published repeatability data from the Atherosclerosis Risk in Communi-
ties study, approximately 40% of patients will move
from HFmrEF to HFrEF or HFpEF in repeated anal-
ysis. The agreement for correct classification of the HF category was substantial, with
a κ of 0.73, and all of the inconsistencies between HF
classification by telemedicine and the reference
related to HFmrEF versus HFrEF or HFpEF. The
prevalence of HFpEF in the study population
was similar to what has been shown other HF
populations. The agreement with respect to estimation
of the LV filling pressure was good, with mis-
classification by the telemedical approach in only
17%. Studies performing similar tasks with repeated
echocardiograms are scarce, but our data were similar
to a study evaluating agreement between echocardiog-
aphers in 105 single echocardiograms.

The views and parameters included in the limited
echocardiographic examination were based on the
need for a proper assessment of a patient with HF,
allowing for classification of subtypes and an assess-
ment of the LV filling pressure. These are less than
what is recommended for a comprehensive echocar-
diogram but substantially more than what is included
in focused cardiac ultrasound.

Very little research has been done in which person-
nel not previously skilled in echocardiography performed
echocardiographic recordings with interpretation by
specialists, but the results are promising when compared
to, for instance, the robotic-arm approach. This
approach differs from the training of echocardiography
technicians and sonographers, as the nurses did not per-
form quantitative analyses but only dedicated recordings
without interpretations of the recordings. The nurses
had years of clinical experience evaluating the volume
status with handheld ultrasound devices but had not per-
formed echocardiography until training for this study.
This confirms previously shown results aiming to imple-
ment telemedicine to overcome geographic challenges.
Thus, a limited echocardiographic examination by
nonexperts can achieve quality that allows for a reliable
assessment. Considering the efforts and costs to
transport patients to a hospital with an available specialist
versus the efforts and costs of training nurses, the study
results can justify implementation into everyday clinical
practice.

Limitations
The aim of the study was to evaluate the LV function,
volume status, and indices important for classification
of subpopulations of HF. Thus, the results cannot be
generalized for other tasks. The agreement between
the methods for determination of an elevated filling
pressure was not validated invasively; thus, only the
agreement of the telemedical approach with the refer-
ence echocardiography could be assessed.

Most of the patients had previous echocardiographic
examinations at the same hospital. The reference cardi-
ologist had access to previous echocardiographic record-
ings. The out-of-hospital cardiologist who performed the
interpretation of the nurses’ recordings was blinded to all
data from previous echocardiograms and medical
histories, and it is not likely that the reference echocar-
diographic examination was influenced by previ-
ous echocardiography. Thus, we find it unlikely that
the knowledge of previous echocardiograms biased
the results, as the complete blinding of the tele-
medical cardiologist interpreting the echocardiograms
would, if having any influence, tend to introduce a
negative bias, which was not observed. The limited
echocardiograms recorded by nonexperts described
here should not be considered equal to comprehen-
sive echocardiography by experts. However, the goal-
directed examinations presented in this study add
valuable quantitative information for clinical decision
making, which may guide therapy beyond what is
achievable by semiquantitative cardiac ultrasound
from handheld devices.

Conclusions
Tele-echocardiography, in the form of image acquisi-
tion by registered cardiac nurses supported by
interpretation by a cardiologist, is feasible and pro-
vides reliable results of central indices for quantifica-
tion of left-sided cardiac size and function, HF
classification, and LV filling pressures. Implementing
tele-echocardiography at remote locations where
echocardiography experts are not available may improve diagnostics and therapy.

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