Improved workflow, sonographer productivity, and cost-effectiveness of echocardiographic service for inpatients by using miniaturized systems

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Aims The aim of this study was to assess the cost-effectiveness of using certified sonographers and miniaturized echocardiography systems to perform echocardiograms at bedside in comparison to moving inpatients from the admission department to the echocardiography laboratory (echo-lab).

Methods and results From 26 September 2005 to 27 October 2005, 112 patients admitted in six hospital wards connected through a 100 Mbit LAN to the echo-lab were scanned within the admission ward by sonographers using a miniaturized echo system. Logistical data were collected and results were compared with those obtained from 194 consecutive patients coming from the same wards and studied in the echo-lab with high-end machines between 8 March 2005 and 15 April 2005. Performing echocardiograms in the admission department avoided long waiting time of the inpatients in the echo-lab before and after the study, increased the percentage of patients studied within 3 and 5 days from request (88 vs. 77% and 100 vs. 95%, respectively; \( P = 0.03 \)), increased both sonographer (by 33.9%; \( P < 0.001 \)) and echo-lab productivity (by 41%; \( P < 0.001 \)), and reduced costs of echocardiograms by 29%.

Conclusion Implementation of digital echocardiography, certified sonographers, and a miniaturized echo system allowed improvement of the cost-effectiveness of the service provided by the echo-lab for inpatients, and avoided patients' discomfort derived from prolonged waiting time before and after the exam.

KEYWORDS
Echocardiography; Organization; Cardiac sonographer; Cost-effectiveness; Digital echocardiography; Miniaturized echocardiography system

Introduction

Echocardiography is an invaluable diagnostic tool in daily cardiology practice,\(^1\) and moving inpatients needing echocardiogram to the echocardiography laboratory (echo-lab) is usually required by present organization of hospital care services.\(^2\) Standard echocardiographic equipments, while performant, are bulky and weight >200 kg, and are difficult to manoeuvre. Therefore, performing the echocardiographic studies directly at bedside is unfeasible in the majority of cases and may cause damage to costly equipment and injury to personnel. As a result, this procedure is reserved only for patients that cannot be transported because of their clinical status or because of special logistical conditions.

Moving inpatients to the echo-lab causes patients' discomfort and increases hospital service costs, since requires porters, it is associated to delays in exam delivery and overcrowding of the echo-lab, and annoys the patients who have to wait out of the echo-lab before and after the exam.\(^2\) These limitations are particularly striking in multiple-stands hospitals.

At present, no study evaluating the costs of this organizational model has been published, neither cost-effectiveness of alternative models has been assessed. The aim of the present study is therefore to assess the cost-effectiveness of using certified sonographers and a miniaturized echocardiography system to perform echocardiograms directly at bedside in comparison to moving inpatients from admission departments to the echo-lab.
Methods

Logistics

The study took place at a 790-bed tertiary-care multiple-stand University Hospital (Figure 1). Each stand is connected to the others through underground tunnels used for carriage of goods and patient transportations. Echo-lab and cardiothoracic surgery department are located in different floors of stand no. 5; cardiology department, coronary care unit, emergency medicine department, emergency room and intensive care unit are located in stand no. 1 far ~150 m from the echo-lab; while clinic of infective diseases and internal medicine department are located in stand nos 9 and 8, far ~1300 and 1500 m from the echo-lab, respectively.

The echo-lab is a full digital one. A 100 Mbit Ethernet local area network (LAN) connects most of hospital wards and the echo-lab to a dedicated PACS (COMPACS, MediMatic s.r.l, Genoa, Italy) able to accept images in DICOM format.

Study design

The study was prospectively carried out in two phases. Phase 1: from 8 March 2005 to 15 April 2005, all inpatients hospitalized in departments connected to the LAN and referred to our echo-lab for standard echocardiographic studies were enrolled.

Echocardiograms were performed in the echo-lab by certified sonographers (L.D.M. and R.C.), using three high-end ultrasound scanners (Vivid 7 Dimension, GE Healthcare, Horten, Norway and Megas, ESAOTE S.p.A., Florence, Italy). Exam acquisition and storage procedures complied with our echo-lab internal protocols. Immediately after the end of the exam, images and measurements were sent through the echocardiography PACS to the echo-lab’s review workstations via LAN. The exam was reviewed by cardiologists with a level 3 of competence in transthoracic echocardiography (L.P.B. and P.G.), using the same software for image reviewing and reporting (COMPACS).

During June and July 2005, our sonographers were trained to use the miniaturized echocardiographic system (Vivid i, GE Healthcare) (Figure 2).

The Vivid i is a miniaturized digital echocardiography system owning the same functionality and performance of the full-featured, larger-scale Vivid 7 system (GE Healthcare), but in a portable design that weighs 30 times less. This system has a compact 12’ × 15’ × 3’ size and weighs ~5 kg. It operates on a rechargeable lithium ion battery or alternating current. It is equipped with wide band phased-array transducer technology for M-mode, two-dimensional (2D), colour and Doppler imaging and with an integrated software (EchoPAC, GE Healthcare) for image data review, analysis, patient archive, and reporting capabilities. Images and measures can be stored on a 60 GB internal hard-disk, on external magnetic supports (CD, DVD, and flash cards) and can be sent to a remote file server, either as raw-data or as DICOM format.

Phase 2: from 26 September 2005 to 27 October 2005, as soon as request forms for standard Doppler echocardiography were received from the same hospital departments who participated to Phase 1, exams were performed by the same sonographers as in Phase 1 at bedside for patients unable to walk and in a dedicated room within the admission ward for walking patients, using the same protocols for image acquisition and storage used during Phase 1.

Immediately after the end of the exam, images and measurements were sent to the echo-lab through the LAN and reviewed by the cardiologists (L.P.B. and P.G.), using the same software for image reviewing and reporting used for studies performed in the echo-lab. When the last patient of a department was scanned, sonographer had to wait echo-lab’s cardiologist approval for completion, accuracy, and overall study quality before moving to the next department.

The design of the study was approved by the local Ethics Committee, and informed consent was obtained from all participants or their legal representatives.

Data collection

Demographic and clinical characteristics of the study population and reasons for the echocardiogram were systematically collected. Furthermore, logistical data of each exam were gathered (i.e. time intervals between the request for echocardiogram and its execution, exam duration, and number of exams performed after patient’s discharge). Additional data were collected both during Phase 1 (how the patient was carried to the echo-lab, travelling time from his/her admission department to the echo-lab, number of phone calls to hospital porter service to take the patient back, and travelling time from the echo-lab to the admission department) and during Phase 2 (sonographer’s travelling time from the echo-lab or the admission department where he performed the last exam to destination department and travelling time from the admission department where the sonographer performed the last exam to the echo-lab).

Figure 1 Schematic draw showing the location of the various stands of Ospedale Universitario di Udine. Each stand is connected to the others through underground tunnels used for carriage of goods and patient transportations. Echo-lab is located in stand no. 5 together with cardiac surgery and cardiology diagnostic services (see text for details).
Continuous variables were summarized as mean (standard deviation) or as median (25th–75th percentile range), when not normally distributed. Categorical variables were summarized as absolute numbers (percentages). Data collected during study Phase 1 and 3 were compared using the $x^2$ test for discrete variables, Student’s $t$-test for normally distributed continuous variables, and the Mann–Whitney U-test for non-normally distributed continuous variables using SPSS software (version 12.0, SPSS Inc., Chicago, IL, USA) by a specialist in health economics (S.S.).

Results

Phase 1: a total of 194 patients were enrolled. Table 1 shows their demographic and clinical characteristics, the department where they were hospitalized, the most common referral questions for transthoracic echocardiography, and how they were carried to the echo-lab.

Seventy-seven percent of the exams were performed within 3 days since they were required, and 95% within 5 days; 8.4% of the exams were performed after patient’s discharge, and patients had to come back to hospital to have their echo-study (Figure 3).

As shown in Figure 4, supplying the service (including the time required for carrying the inpatients) needed 1 h and 43 min on average (95% CI: 60–154 min), while echocardiographic studies lasted 23 min on average (95% CI: 17–38 min). Carrying patients to the echo-lab and to the admission department, at the end of the exam, required on average 12 min (95% CI: 9–15 min), respectively. Patients stayed in the waiting room on average 35 min before the exam (95% CI: 12–116 min) and 21 min after the exam (95% CI: 15–72 min), waiting for the hospital carrier service. In 165 cases (85%), the echo-lab had to urge porters to carry the patients at least once, and in 21 cases (11%), porters were urged at least twice.

During the Phase 1, 818 echocardiograms were overall performed by the echo-lab (including 24 stress echocardiograms and 38 transoesophageal echocardiograms). The productivity of the echo-lab was of 57% (9.7 exams/day per sonographer/scanner), accounting a theoretical maximal productivity of 16.9 exams/day per scanner (6 h and 30 min of work/day per sonographer divided by an average duration of exam of 23 min).

Phase 2: during this phase, the study was discontinued between 10 and 15 October for concomitant illness of two sonographers. One hundred and twelve patients were enrolled during this phase of the study (Table 1) Twenty-five percent of the patients were unable to walk. In comparison to the Phase 1 enrolment, during Phase 2 we have eliminated the cardiac surgery department from the list of

### Table 1 Demographic and clinical characteristics of the study population

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 (n = 194)</th>
<th>Phase 2 (n = 112)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69 ± 15</td>
<td>71 ± 13</td>
<td>NS</td>
</tr>
<tr>
<td>Male sex</td>
<td>103 (53%)</td>
<td>62 (55%)</td>
<td>NS</td>
</tr>
<tr>
<td>Most frequent reasons of referral to the echo-lab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>25.3%</td>
<td>25.0%</td>
<td>0.01</td>
</tr>
<tr>
<td>Valve disease</td>
<td>23.2%</td>
<td>9.8%</td>
<td></td>
</tr>
<tr>
<td>Heart failure</td>
<td>11.9%</td>
<td>25.0%</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>6.7%</td>
<td>7.0%</td>
<td></td>
</tr>
<tr>
<td>Arrhythmias</td>
<td>4.1%</td>
<td>6.3%</td>
<td></td>
</tr>
<tr>
<td>Pericardial disease</td>
<td>2.1%</td>
<td>3.6%</td>
<td></td>
</tr>
<tr>
<td>Infective endocarditis</td>
<td>1.5%</td>
<td>3.6%</td>
<td></td>
</tr>
<tr>
<td>Department of origin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiothoracic Surgery</td>
<td>64 (33%)</td>
<td>2 (2%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Internal Medicine</td>
<td>87 (45%)</td>
<td>60 (54%)</td>
<td></td>
</tr>
<tr>
<td>Emergency Medicine</td>
<td>28 (14%)</td>
<td>22 (20%)</td>
<td></td>
</tr>
<tr>
<td>Cardiology</td>
<td>13 (7%)</td>
<td>24 (21%)</td>
<td></td>
</tr>
<tr>
<td>Pneumology</td>
<td>2 (1%)</td>
<td>4 (3%)</td>
<td></td>
</tr>
<tr>
<td>Unable to walk</td>
<td>36 (19%)</td>
<td>28 (25%)</td>
<td>NS</td>
</tr>
<tr>
<td>Carrying to the echo-lab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital carrier service</td>
<td>83 (43%)</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Nurses</td>
<td>95 (49%)</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Parents</td>
<td>16 (8%)</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2** Vivid I (GE Healthcare, Milwaukee, WI, USA) is a lap-top sized echocardiography machine that can be easily transported and used in every department in the hospital. Despite its limited size, it has all the modalities of a standard echocardiographic machine.

**Figure 3** Distribution of time required from request arrival to perform the echo studies for inpatients.

Cost-effectiveness of miniaturized echo systems

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enrolling departments because the number of requests from cardiac surgery was so high that it would have monopolized the echocardiographic machine.

Eighty-eight percent of the exams were performed within 3 days since they were required, and 100% within 5 days (\(P = 0.06\) and \(P = 0.07\) when compared with the corresponding figures in Phase 1, respectively). Only 2.6% of the exams should have been performed after patient’s discharge (-69% when compared with the post-discharge exam performed in Phase 1, \(P = 0.07\)).

On average, the sonographer performed four exams per department daily. As shown in Figure 5, supplying the service needed 64 min (95% CI: 50–72 min). The mean time spent by the sonographer to move from the echo-lab to the patient’s department and to come back to the echo-lab was 10 min (95% CI: 7–13 min), respectively. The sonographer awaited on average 15 min (95% CI: 6–23 min) before doing the exam mostly because the patient or the dedicated room was temporary unavailable due to ongoing medical visit. When the last patient of a ward was scanned, sonographer waited on average 9 min (95% CI: 8–12 min) for the echo-lab approval to leave the department; \(L_1\), travelling time from admission department to echo-lab; \(L_2\), travelling time from the echo-lab to the admission department.

Considering the same number of exams (112) and exams of similar complexity as in Phase 1, the overall improvement in efficiency during Phase 2 was of 11 h and 5 min (i.e. 6 min/exam, \(P < 0.0001\)). However, more complex exams were performed in Phase 2 (Table 1) and they absorbed about half of this improvement (5 h and 29 min; i.e. ~2 min/exam).

No failure in image and data transmission through LAN occurred, neither the echo-lab’s cardiologist had to move from the echo-lab to complete any echo-study. Transmission of the echocardiographic studies through the LAN required on average 2 min and 38 s.

Five (4%) studies had to be repeated using high-end machine in the echo-lab to collect 3D images (three patients), to better evaluate disappearance of small apical thrombosis in myocarditis (one patient), and to inject contrast in one patient with suspected interventricular septum defect due to closure patch detachment.

During the Phase 2, 793 echocardiograms were overall performed by the echo-lab (including 30 stress echocardiograms and 26 transoesophageal echocardiograms). The productivity of the echo-lab was then of 81% (15.8 exams/day per scanner; +41% when compared with Phase 1, \(P < 0.0001\)). The improvement in productivity of the echo-lab by 41% was enough to cause a reduction of the cost of each exam from 230€ to 163€ (~29%).

Also the productivity of the sonographer increased; the mean number of studies performed by the sonographers during Phase 2 was 7.9/die, when compared with 5.9/die during Phase 1 (~33.8%; \(P = 0.001\)).

**Discussion**

Our results show that implementation of digital echocardiography and use of certified sonographers and miniaturized echo systems allowed improvement of workflow and cost-effectiveness of the service provided by the echo-lab for inpatients, and avoided patients’ discomfort derived from prolonged waiting time before and after the exam.

The rapidly expanding clinical application of echocardiography over the past decades has been brought about by progress in technology combined with a broader understanding of its clinical applicability.\(^9\) Echocardiographic imaging now rivals or exceeds commonplace techniques such as chest radiography and electrocardiography for information about cardiac morphology and function and physiologic performance.\(^9\) The expansion of applications of echocardiography in the past decades has been accompanied by a marked growth in its utilization rate, contributing to the rising of health-related expenditures.\(^{10,11}\) As a direct consequence, echo-labs are overcrowded, with prolonged waiting lists for both inpatients and outpatients, and potential significant time delay in getting crucial diagnostic information. These problems are particularly striking in tertiary-care or university hospitals, where disease complexity of inpatients is higher, requiring a large number of diagnostic procedures and more accurate echocardiographic studies, with additional
haemodynamic measurements. Furthermore, echo-labs usually have to perform also a large number of time-consuming special exams (i.e. echocardiograms with contrast, 3D studies, stress echocardiograms, transoesophageal echocardiograms, and echocardiograms as ad to interventional procedures) for patients with known heart disease.

In clinical practice, organizational models that require moving inpatients from admission department to the echo-lab are not cost-effective and have negative impact on patients’ quality of life, as it can be deduced by the results of the present study. Moreover, this organizational system caused significant discomfort to inpatients, since they had to await a long time before and after the exam, as a consequence of the overcrowding of the echo-lab and of the hospital porter service. This waiting is expected to be particularly painful for frail elderly patients, especially if not self-sufficient. Furthermore, other diagnostic and therapeutic procedures are temporarily blocked because of the unavailability of the patients, with potential harmful delays and prolongation of hospitalization.

The implementation of an alternative organizational system based on digital echocardiography, certified sonographers, and miniaturized echo system allowed to change the paradigm of moving inpatients to the echo-lab. It was the echo-lab which moved to the patient bedside or admission department and the echo service was delivered directly in the admission department. The results of this study showed that this model is able to improve the cost-effectiveness of the service provided by the echo-lab and to avoid patients’ discomfort derived from prolonged waiting time before and after the exam, an important issue for patients’ perspective. This was also possible because, conversely from previous hand-held systems, present miniaturized echo systems like Vivid I are fully equipped with all modalities (M-mode, 2D, spectral Doppler, colour Doppler, and pulsed-wave Tissue Doppler), full measurement, and archiving capabilities (worklist, DICOM and raw-data files) needed for a complete echocardiographic study that can address 90% of clinical problems of inpatients (i.e. left ventricular function and valve function). High-end systems can be reserved for more sophisticated and technically demanding studies (i.e. 3D, stress-echo, tissue velocity imaging, contrast, etc.) and for research.

During Phase 2, the productivity of the echo-lab increased by 81%, mainly as a consequence of the increased productivity of the sonographers. The improvement in productivity was enough to cause a reduction of the cost of each exam by ~29%. Anyway, the reduction of overall costs for the hospital service is probably underestimated. Several additional advantages may be found with performing adequate quality, accurate, and complete studies at bedside using low-cost miniaturized echocardiographic machine. Full-sized top-of-the-line machines are available longer for special echocardiographic studies. Faster delivery of the echocardiography service directly in the admission department allowed indeed to reduce the number of exams performed after patient’s discharge and to make the patient earlier available for other diagnostic or therapeutic procedures. A reduction in workload of the hospital porter service is also to be taken into account. As a result, porters become available to transport patients for procedures other than the echocardiography exam, with benefits also for other expensive resources such as computed tomography and magnetic resonance scans, and operating rooms. Furthermore, nurses are no more involved in performing porter services, being able to support much more the healthcare within their department.

Transition to an all-digital echo-lab is a necessary requirement to achieve these results. The advantages of digital echocardiography are demonstrated in improved image review and quantification. Examination review is improved by higher/stable image quality, random access to images/views in a study, and rapid comparison with prior studies.

Cardiac sonographers are also essential for the effective development of this organizational model. Finally, achieving the results of Phase 3 required the implementation of a miniaturized echocardiography system. After the first experiences of the 1970s, the widespread of hand-held echocardiography systems opened controversy about their diagnostic accuracy, the opportunity to establish the clinical scenario where they should be utilized and the identification of the potential users and the needed competence level. In most cases, hand-held ultrasound devices are used to complete the clinical assessment, enhancing the art of bedside physical examination by increasing diagnostic accuracy, detecting disease at an earlier stage, and improving triage and referral of patients. However, their diagnostic performance and archiving capabilities are generally inferior to standard echocardiography, and they cannot be used to obtain a full echocardiographic study, even if there appears to be good concordance at least for some conditions. The implementation of new generation miniaturized echocardiography systems (like Vivid I) overcomes these limits. However, our results cannot be extended to hand-held ultrasound systems.

Conclusions
An organizational model based on a full-digital digital echo-lab, certified sonographers and miniaturized echocardiographic machines allowed improvement of the cost-effectiveness of the service provided by the echo-lab for inpatients, and avoided patients’ discomfort derived from prolonged waiting time before and after the exam. The organizational model we developed was urged by the specific logistic needs of our tertiary-care University Hospital. However, this model can be easily applied to other scenarios: mobile echocardiography services to allow efficient delivery of echocardiograms in regional hospitals and clinics lacking of echocardiographic facility; home-care for severely ill patients, teleconsulting, and second opinion request.

Conflict of interest: none declared.

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References


