

# Mobile Echocardiography



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Heart failure, valvular heart disease, cardiomyopathies and echocardiography are areas of special interest to Dr. Steensgaard-Hansen. He has worked in the field of echocardiography since 1978 and performed more than 30,000 TTE's and 5,000 TEE's. He is very interested and committed to the systematic education and training of physicians and technicians in highly standardized state-of-the-art clinical echocardiography, including transthoracic and transesophageal Live 3D and Speckle Tracking.

With the recent introduction of all-modality, portable echocardiography systems, offering high-end image quality and full compatibility with digital echocardiography networks, mobile echocardiography has entered a new, highly promising era. Systematic and well organized use of these high-end portable systems for complete bedside echocardiographic examinations will most likely improve workflow and productivity in the echo lab. Furthermore, mobile echocardiography services outside the hospital will greatly benefit from the performance and flexibility of these machines.

This paper describes the milestones in mobile echocardiography and presents the wide spectrum of activities and possibilities in mobile echocardiography within and outside the hospital. Also, the impact of mobile echocardiography on workflow and productivity in the echo lab will be discussed. Finally, the paper offers experiences from testing the Philips CX50 high-end portable

echocardiography system, and views on the further development of mobile echocardiography.

## **The early hand-carried echocardiography systems**

Early in the history of echocardiography, attention was brought to the unique possibilities in bedside cardiac imaging, and soon the need for in-hospital mobile echocardiography was widely recognized. Already in the late 1970s and early 1980s, out-of-hospital mobile echocardiography was introduced.

For many years mobile echocardiography within as well as outside the hospital implied taking a standard full-size machine to the patient. With the development of early miniaturized systems, like the Optigo, mobile echocardiography entered a new era, since these minute systems could be carried anywhere in the hospital as well as in the community. They soon proved valuable

# PHILIPS

especially in relation to limited, focused echocardiographic examinations in the intensive care unit, the out-patient clinic, and on ward rounds, but also in performing echocardiography as part of screening for heart failure or left ventricular hypertrophy outside the hospital, in community-based studies or programs [1]. However, these early hand-carried machines only provided imaging and color mapping, and the image quality was often inadequate. They should be used only as an ultrasonic stethoscope for immediate answers to the important clinical questions listed in Table 1.

Table 1: Clinical questions addressed in limited, focused echocardiographic examinations.
<ul style="list-style-type: none"> <li>• exclusion of pericardial effusion</li> <li>• exclusion of obvious and significant valvular disease</li> <li>• assessment of left ventricular size, hypertrophy, and wall motion abnormalities</li> <li>• “eyeball” estimates of LVEF</li> <li>• estimates of right ventricular function</li> <li>• estimates of significant pulmonary hypertension</li> </ul>

In direct comparison, the small hand-carried systems were found to be inferior to standard full-size machines in the evaluation of critically ill patients [2]. This should come as no surprise since the clearly inferior image quality was a tough match to the extraordinary challenges frequently encountered performing echocardiography on critically ill patients (dyspnoea, assisted ventilation, suboptimal body position etc.).

Moreover, the lack of important echocardiographic modalities, the severely limited capability for quantitative analysis, and the difficulties in transferring the images obtained to the server in a digital echo lab all proved to be significant shortcomings of these early hand-carried machines.

### Second generation all-modality, portable echocardiography systems

These machines represented an important improvement in mobile echocardiography since they were complete with respect to echocardiographic modalities, and the tools for quantitative analysis were improved considerably. Furthermore, they were relatively



cheap compared to state-of-the-art full-size machines, and the costs related to a portable study were considerable smaller compared to a standard echocardiographic study.

In a study, published this year, the effects of systematic use of hand-carried echocardiography systems for complete bedside echocardiographic studies were analyzed with respect to workflow, productivity and cost-effectiveness [3]. The echocardiographic examinations were performed at the bedside in admission wards and digitally transferred to the echo lab. The results described are remarkable:

- The productivity of the sonographers and the echo lab were significantly increased (34% and 41% respectively).
- The costs of echocardiograms were reduced by 29%.
- The waiting time of the in-patients for echocardiography in the echo lab was reduced.
- Long waiting time in the echo lab before and after the study was avoided.

However, in general the performance of these machines and their impact on costs and workflow were hampered by inadequate image quality. Many patients had to have a complete standard echocardiographic examination on a high-end, full-size machine later on.

### High-end portable echocardiography systems

Recently, the concept of mobile echocardiography has changed considerably, with the introduction of portable echocardiography systems offering high-end image quality, a complete range of echocardiographic modalities, tools for comprehensive quantitative analysis, and full compatibility with digital echocardiography networks. Now, diagnostically reliable focused examinations, as well as complete and definitive echocardiographic examinations, can be performed with portable machines anywhere within the hospital, as well as outside the hospital.



Beneficial effects on workflow, productivity and cost-effectiveness are not hard to imagine or predict, but further systematic studies and analysis of these issues are certainly desirable. However, it is only to be expected that the actual results and benefits might differ considerably depending on the local institutional infrastructure, logistics, organization and established practices. Nevertheless, it would be highly surprising if the systematic and well organized use of high-end portable echocardiography machines for complete bedside echocardiographic examinations fails to improve workflow and productivity.

#### Philips CX50 – tests and experiences

The Philips CX50 is a new, fully digital, high-end portable echocardiography machine, introduced by Philips in 2008. We have tested the CX50 in our institution over a period of 7 months, from late August 2008, including a comparative study on 140 patients having echocardiographic examinations on the CX50 in addition to complete routine examinations on our standard machines (Philips iE33 Vision 2008/2009). Also, the CX50 has been used for mobile echocardiography, including studies on immobile patients in their private homes. It should be emphasized that our testing program was not designed for systematic and quantitative analysis of the consequences of mobile echocardiography on workflow and productivity in our echo lab. We were, however, left with a strong impression that the systematic use of high-end portable echocardiography systems for mobile echocardiography improves workflow and productivity in the echo lab – provided that the studies performed are complete echocardiographic studies.

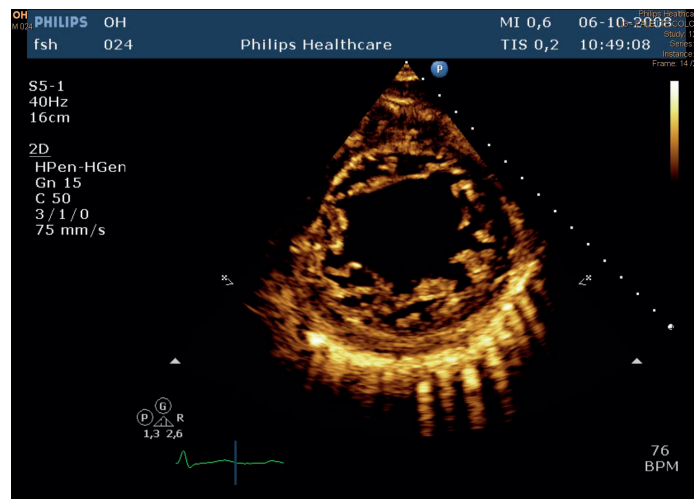
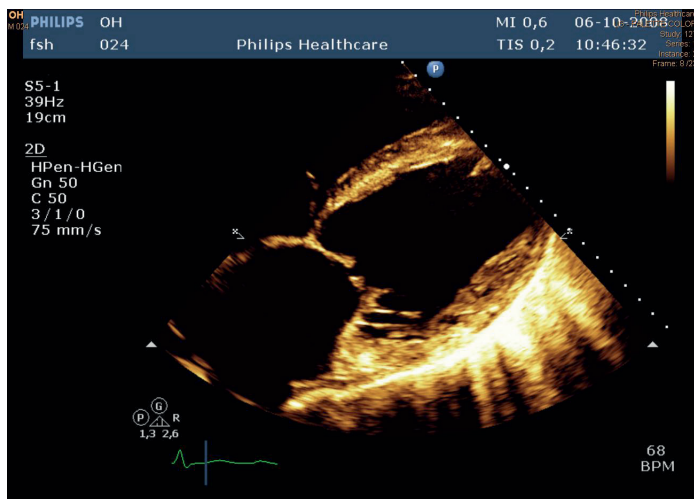
#### Philips CX50 offers genuine high-end mobile echocardiography

Based on our experiences with the CX50 we can conclude that:

- The CX50 has proven absolutely reliable with no break-downs at all. This is very important since mobile echocardiography imposes extraordinary strain on the machine.
- The CX50 and the external power box are indeed highly portable. If an electrical power outlet is unavailable, the CX50 is capable of at least 30 min. of service on battery power.
- The CX50 can be mounted on a cart, which is very stable and so much easier to handle and maneuver compared to a full-size system. From an ergonomic point of view, the cart is a comfortable and flexible platform for the machine performing in-lab as well as bedside or intraoperative echocardiography.
- The machine has a sensor based automatic adjustment of the screen, which copes very well with major changes in light conditions in the examination rooms. This is an important feature in mobile echocardiography.
- The CX50 is very easy to use, and the ergonomics are very good for a portable system, although, not on a par with the ergonomics of a full-size system.
- It has never been easier to obtain high quality 2D images than on the CX50 - even for the less experienced echocardiographer. This is expected to be of the utmost importance, not least in relation to the extraordinary technical challenges frequently encountered performing emergency echocardiography on critically ill patients.

The 2D image quality on the CX50 is very, very impressive indeed, even in direct and critical comparison with the iE33 Vision 2008/2009. In some cases the visualization of anatomical details was actually superior on the CX50.

- As regards echocardiographic modalities, the CX50 is definitely a complete machine.
- We prefer to review and analyze the studies obtained on the CX50 in Xcelera and QLAB following transfer of the studies to our server (100 Mbit LAN). However, for immediate on-site analysis, the available measurements and calculations are adequate and well functioning. If needed, it is fairly easy to customize measurements and calculations and define new calculations.
- We tested the CX50 as an integrated part of the digital echocardiography network in our echo lab. We have not encountered any problems at all with respect to transfer of the studies to the server (via LAN or wireless, as described on p.12-13) or review and analyse off-line on digital workstations.



**Table 2: Diagnostic performance of CX50 vs. iE33 - reasons for echocardiography**

- heart failure or dyspnoea of unknown cause (66)
- valvular or suspected valvular disease (31)
- dilated or hypertrophic cardiomyopathy (8)
- hypertension (11)
- systemic embolism (12)
- others (12)

**Tabel 3: Diagnostic performance of CX50 vs. iE33 - echocardiographic diagnoses were 100% concordant in 139 out of 140 cases**

- left ventricular systolic dysfunction (24)
- left ventricular diastolic dysfunction (17)
- left ventricular hypertrophy (15)
- valvular disease (hemodynamic significant) (26)
- hypertrophic cardiomyopathy (4)
- pulmonary hypertension (11)
- aortic aneurysm (3)
- normal or trivial findings (39)

### Diagnostic performance of the CX50 versus the iE33

In 140 randomly selected adult patients, we compared the performance of the CX50 and the iE33 Vision 2008/2009. Immediately following the routine examination (iE33), a second study was performed using the CX50. The former was analyzed and reported as usual. The latter was analyzed after completion of the entire series of patients and without prior knowledge of patient ID or the results from the routine examination.

The studies were performed by a highly experienced cardiologist and two very experienced echo technicians. The same cardiologist analyzed all the CX50 studies. The reasons for echocardiography are listed in Table 2, and an overview of the echocardiographic diagnoses is shown in Table 3.

In one case, the discreet flow across a small PFO could be identified with Color Doppler on the iE33 but not on the CX50.

For the individual quantitative parameters, differences were very small and well within what could be expected in this pretty ideal situation:

- temporal variability virtually eliminated
- both examinations (iE33 and CX50) performed by the same echocardiographer
- additional practical advantage of performing the CX50 study immediately after the iE33 study, in terms of knowledge of optimal views, projections, settings and adjustments

It is not within the scope of this paper to present and discuss the intra-observer variability data in detail.

### Mobile echocardiography – a wide spectrum of activities

Mobile echocardiography comprises a wide range of echocardiographic activities within and outside the hospital as shown in Figure 2.

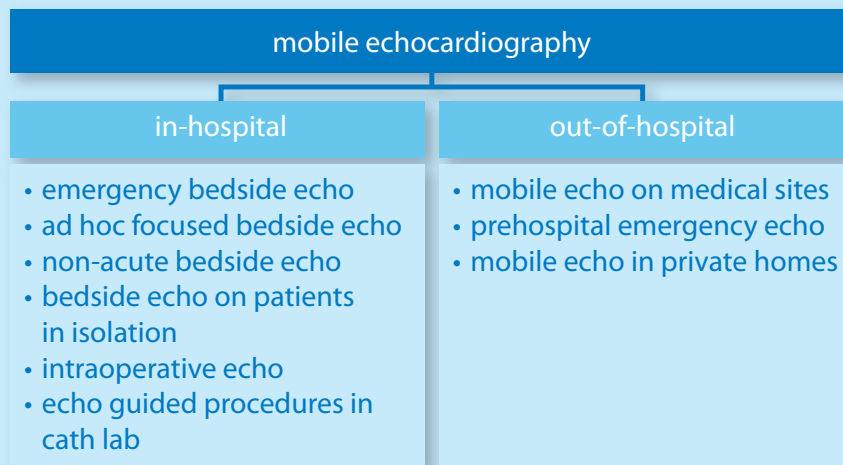


Figure 2:  
the spectrum of activities in mobile  
echocardiography

## Mobile echocardiography in-hospital

### Emergency bedside echo

The ability to provide immediate information of essential importance to the treatment of critically ill patients remains a major strength in the field of echocardiography. This could be screening for severe structural heart disease (myocardial, valvular etc.) and assessment of left ventricular function on a patient in pulmonary edema or suspected cardiac tamponade due to intrapericardial hemorrhage following open heart surgery – just to mention a few examples.

Taking place mainly in the intensive care unit, the semi intensive care unit, the recovery room, and the emergency room these, most often focused, echocardiographic studies are performed not only by cardiologists and sonographers, but to a greater extent by anesthesiologists or intensive care specialists. Focused echocardiography being performed by anesthesiologists and intensive care specialists is a logical development in echocardiography that most certainly ought to be supported as much as possible by the national and international societies of cardiology – not least in terms of well organized, systematic education and training in focused echocardiography.

Hand-carried echocardiography systems are ideal and highly flexible under these circumstances, exemplified by intense simultaneous activity by several members of the intensive care staff. The echocardiographer is frequently facing extraordinary technical difficulties performing echocardiography under time pressure on critically ill patients lying in echocardiographically suboptimal body positions. These are factors calling for a portable echocardiography system that is very easy to use. It should be possible to roll in the system on the cart, or to hand carry it to the site where emergency bedside echo is to be performed.

Furthermore, it should be very easy to obtain high-end image quality with a minimum of adjustments. It is important that studies can be transferred via LAN to the digital network in the echo lab for immediate review by or a second opinion from an experienced cardiologist. The CX50 certainly meets all these criteria, and the machine is ideally suited for emergency bedside echo.

### Ad hoc, focused bedside echo

In the out-patient clinic and on a ward round, ad hoc, focused bedside echo rapidly provides important information in addition to the clinical examination (see Table 1). Such echocardiographic examinations may speed up the diagnostic process considerably and improve patient care. However, these studies are usually incomplete, and unless performed in order to monitor an already properly diagnosed disease, a complete echocardiographic study will have to be performed later on.

In this context, the completeness as regards echocardiographic modalities, the image quality, and the full compatibility with digital echocardiography networks provided by high-end portable systems, like the CX50, is most certainly attractive.

### Non-acute bedside echo

The workflow and productivity in the echo lab may benefit considerably from non-acute bedside echo being performed in the wards, including the admission wards, and in particular on immobile patients [3]. These routine studies are usually complete echocardiographic examinations performed by sonographers or cardiologists. Once more, the virtues of high-end portable systems, like the CX50, facilitate the execution of complete bedside echocardiographic studies. Furthermore, the usefulness of these studies benefits from the impressive image quality, which is on a par with high-end full-size systems.



Bedside echocardiography increases the physical strain on the echocardiographer compared to standard examinations in the echo lab. The latter are, or ought to be, characterized by well positioned patients, electrically adjustable couches designed for echocardiography, ergonomic chairs and the use of high-end, full-size machines. Performing mobile bedside echocardiography all day long might very well impose the sonographers to an increased risk of injuries.

#### Bedside echo on patients in isolation

Echocardiography on patients placed in isolation due to contagious disease or severe immune incompetence is very often troublesome and time consuming.

Important reasons for echocardiography under these circumstances include heart failure and suspected endocarditis or pericardial effusion. These complete transthoracic or transesophageal studies are performed by cardiologists or sonographers.

Special attention has to be paid to the risks of exposing the patient to infectious material or exposing subsequent patients to infectious material from the patient in isolation. In this context it is a lot easier to handle a portable echocardiography system placed on a clean stainless steel table than a standard full-size machine. Single-use, transparent covers for the control panel and the use of transducer sheets are appropriate.

It is very important that these studies are confirmed as complete and of sufficient quality, before the echocardiographer and the echo machine leaves the room. Thus, it is a great advantage if the study, whenever needed, can be transferred via LAN to the digital network in the echo lab for immediate review or a second opinion.

The CX50 seems ideally suited for bedside echo on patients in isolation.

#### Intraoperative echo and echo guided procedures in the cath lab

These studies demand high-end image quality. However, the physical size of a high-end full-size echocardiography system is very often a major challenge in the cath lab or the operating theatre and a source of inconvenience for the staff involved in the procedure in question.

In a limited number of procedures, we have found that the CX50 mounted on the cart is highly suitable for intraoperative echocardiography.

Working with several TEE probes in parallel, the CX50 is easily moved from one operating theatre to another. As regards image quality, the CX50 comes really close to the iE33. Due to the lighting conditions in an operating theatre and in order to facilitate the presentation and discussion of images with the surgeons, it might be advantageous to connect the CX50 to a well positioned, high resolution, external monitor. It is a great advantage that the study, whenever needed, can be transferred by LAN to the digital network in the echo lab for immediate review by or a second opinion from an experienced cardiologist.

These considerations probably apply for echo guided procedures in the cath lab (device closure of atrial septal defects etc.) as well. However, I have no personal experience as regards the performance of the CX50 in this context.

Thus, the CX50 is ideally suited for intraoperative echocardiography and possibly for echo guided procedures in the cath lab as well. However, it would be a very attractive and clinically highly relevant innovation if Live 3D TEE is supported by the CX50 in the near future.

#### Out-of-hospital mobile echocardiography

##### Mobile echocardiography on medical sites

Mobile outreach echocardiography services were introduced in the United States already in the late 1970s and early 1980s. Especially in some very large countries like United States, Canada and Australia such services are nowadays well established and very well organized [4]. Although the number of cardiologists has increased considerably over the last couple of decades, the access to cardiologists in rural areas and in regional hospitals remains insufficient in many countries. Mobile outreach echocardiography services, such as complete adult and pediatric TTE and TEE and sometimes stress echo, are performed in regional hospitals or in primary care clinics on a scheduled basis by cardiologists and specially trained sonographers. If echocardiographic equipment of sufficient quality is unavailable at the location, the team will have to provide the ultrasonography machine. In this context, high-end full-size machines are very troublesome and call for customized vans.

In this context, the completeness as regards echocardiographic modalities, the image quality, and the full compatibility with digital echocardiography networks provided by high-end portable systems, like the CX50, is most certainly highly attractive. Optional onsite review or second opinions via digital transfer of the study to the digital network in the echo lab is desirable, but might prove technically impossible in some remote locations.

#### Prehospital emergency echocardiography

Emergency focused echocardiography at the scene of an accident or during transportation of critically ill patients is rightfully attracting still more interest. Reports are mainly based on experiences from individual cases, including cardiac tamponade, but prehospital assessment of cardiac function would be desirable in many instances. Immediate access to echocardiographic information might facilitate emergency treatment at the scene of an incident and the preparation of in-hospital emergency surgery or other highly specialized treatment.

Wireless digital transfer of echocardiographic recordings to the digital network in the echo lab for immediate review by or a second opinion from an experienced cardiologist would be highly desirable in these circumstances.

#### Mobile echocardiography in private homes

It is very troublesome, time consuming, and quite expensive to have immobile patients brought to the out-patient clinic or the echo lab for an echocardiographic examination. Especially in major cities, extending mobile echocardiography services to private homes is a distinct possibility. Naturally, such a service should be restricted to immobile or otherwise severely incapacitated patients, who present incontrovertible indications for echocardiography.

For a number of years, our institution has provided the population in Copenhagen (approximately 1.2 million inhabitants) with mobile services in private homes, including blood samples and ECG. As a consequence of our experiences with the CX50 we have organized and tested a new concept of mobile echocardiography services in private homes:

- The selected patients are scheduled for mobile echocardiography in their private home.
- If needed, the home care service is contacted in order to have the patient ready and prepared for transthoracic echocardiography.

- The examinations are performed by highly experienced sonographers travelling by car bringing along the CX50, external powerbox, a laptop, a high capacity wireless USB modem, and a mobile phone.
- Based on referral diagnosis, additional information provided by the requesting physician, and an interview of the patient, the sonographer prepares a brief clinical summary.
- A complete transthoracic echocardiographic study is performed. For security reasons (wireless transfer, see below), a predefined patient ID based on the patients initials and a consecutive patient number is used.
- In order to reduce the size of the study, 2D and Color-Doppler loops are restricted to one cardiac cycle. For acquisition the sequence freeze, replay, edit loop and acquire (if the loop is accepted) is used in order to avoid technically or otherwise flawed loops and multiple, but basically identical loops. The size of a complete study in standard DICOM format is usually around 70 MB.
- The study is transferred, in DICOM format, to the laptop via a USB stick. Next, the study is compressed to a little more than 50% of the original size without any loss of data (WinZip).
- Using a commercial high-capacity wireless USB modem, the study is transferred to the digital network in our echo lab. This process usually takes 5-7 minutes. By phone, the sonographer informs a cardiologist in the echo lab that the study is available for review within a few minutes.
- Reviewing the study, the cardiologist is in contact with the sonographer and, if needed, with the patient by phone. Additional specific recordings are made on request from the cardiologist.
- The report is completed and forwarded to the requesting physician.

Following a successful test period, we are now ready to launch mobile echocardiography in private homes as a routine service.

#### The next step in mobile echocardiography

Based on the impressive image quality provided by the CX50, the physical size of the machine, and its flexibility in the cath lab or the operating theatre, it would be highly desirable to have Live 3D TEE onboard the CX50.

Performing in-hospital as well as out-of-hospital mobile echocardiography, it is a great advantage if the study, whenever needed, can be transferred to the digital network in the echo lab for immediate review or a second opinion by an experienced cardiologist. As described, this can be done via LAN or a commercial

high capacity wireless USB modem. The upload capacity of the latter is expected to improve dramatically over the next few years (10 MBit per sec.). In that case, wireless transfer will not only be an extremely flexible but also a very swift method for digital transfers of echocardiographic studies.

From this point of view, it seems another great innovation would be for the CX50 to support the use of commercial high capacity wireless USB modems, and the wireless data transfer to the digital network in the echo lab.

Because of its impressive image quality, ease of use and great flexibility, the CX50 really has the potential of becoming a very popular ultrasonographic machine among anesthesiologists and intensive care specialists. They are not only increasingly active in the field of echocardiography, they frequently perform ultrasound guided invasive procedures like percutaneous subclavian or internal jugular vein cannulation. Thus, it might be yet another important innovation if the CX50 could support such ultrasound guided invasive procedures.

### Summary

Mobile echocardiography comprises a wide range of acute and non-acute echocardiographic activities within and outside the hospital. For many years mobile echocardiography implied taking a standard full-size machine to the patient. Thus, in principle mobile echocardiography was greatly facilitated by the development of hand-carried, miniaturized echocardiography systems. However, the performance of the early generations of portable echocardiography systems and their impact on costs and workflow were hampered by severe inadequacies regarding echocardiographic modalities and image quality.

With the recent introduction of all-modality portable echocardiography systems offering high-end image quality and full compatibility with digital echocardiography networks, mobile

echocardiography has entered a new highly promising era. Systematic and well organized use of these high-end portable systems for complete bedside echocardiographic examinations will most likely improve workflow and productivity in the echo lab. Furthermore, mobile echocardiography services outside the hospital will greatly benefit from the performance and flexibility of these machines.

The Philips CX50 offers genuine high-end mobile echocardiography. It is very easy to use, and the 2D image quality is highly impressive even in direct comparison with the state-of-the-art, full-size, Philips iE33 system. With respect to diagnostic performance, the CX50 is definitely on a par with the iE33. Based on the impressive image quality provided by the CX50, the physical size of the machine, and its flexibility in the cath lab or the operating theatre, it would be highly desirable to have Live 3D TEE onboard the CX50. It would also be highly desirable if the CX50 supported the use of commercial high capacity wireless USB modems, and wireless data transfer to the digital network in the echo lab.

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