

Virtual guidance: a new technique to empower point-of-care ultrasound in remote or extreme environments

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Abstract

Purpose Remote guidance techniques have been developed by NASA researchers to allow non-clinicians to perform complex ultrasound examinations on the International Space Station to increase clinical diagnostic capabilities. Real-time or near real-time communication will not be an option for missions beyond the Earth and Moon; non-experts will have to scan autonomously. We investigated the ability of non-experts to perform point-of-care ultrasound in a remote location using “virtual guidance”, consisting of a video-based training and troubleshooting guide to acquire cardiac ultrasound images.

Methods Non-expert operators ($n = 4$) reviewed a short (<15 min) cardiac ultrasound examination training video using dedicated video glasses and an iPod. They then acquired echocardiography scansets on normal, volunteer subjects at Resolute Bay, Canada using a portable ultrasound device. Image quality was evaluated using a scoring system by two experts in echocardiography.

Results Cardiac ultrasound examinations were autonomously completed by four non-expert operators using virtual guidance in under 30 min and judged to be adequate for clinical interpretation. Virtual guidance with the video glasses and streaming examination guide was accepted by all operators as an effective guidance technique for this purpose.

Conclusions Virtual guidance is a novel technique that may allow data acquisition by non-expert operators autonomously when on-site expertise or real time support is not available. Further refinement of the technique should be explored to enhance autonomous medical capabilities in isolated or underserved settings, either on or off the planet.

Keywords Ultrasound · Echocardiography · Remote medical care

Introduction

Evidence published in peer-reviewed literature is driving further expansion and broader recognition of point-of-care ultrasound. In some applications, such as the FAST examination and diagnosis of pneumothorax, the amount of high-level evidence is overwhelming; for other uses, there are variable numbers of publications which show favorable results of newer applications [1–5]. Physicians practicing in limited-resource settings, especially in the absence of alternative imaging capabilities, may be compelled to consider such novel use of ultrasound without strong evidence, realizing that images obtained from a particular patient may be anywhere in the continuum of diagnostic confidence—from non-diagnostic to specific beyond any doubt. Further evidence will likely uphold the merits of rapid, focused bedside techniques in many more conditions than currently recognized.

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Ultrasound equipment is much easier to provide than an expert for its operation in limited resource or remote settings. Human space flight is a stark example of such an environment, where inexperienced or minimally trained astronaut ultrasound operators will most likely not be physicians. A physician's medical knowledge is a reliable quality assurance mechanism which allows real-time anatomic correlation with ultrasound and an assessment of diagnostic confidence.

NASA researchers have used remotely guided ultrasound on the International Space Station (ISS) over the past 8 years with remarkable success [5–7]. The on ground experts guided astronaut operators to obtain diagnostic image sets and research data in a wide variety of applications. The technique of remote guidance requires real-time or near-real-time video transmission and two-way voice interaction. Future exploration class spaceflight will involve greater distances from Earth and will render direct communication impossible. Similar challenges are also encountered in isolated locations on Earth.

Our research team developed the technique of “virtual guidance” to enable autonomous, point-of-care ultrasound for use in situations without direct communication capabilities. This novel approach is based on the premise that short, high-impact audiovisual content, which demonstrates the procedure, target imaging results, and troubleshooting in anticipated difficulties, could be used to enable complex ultrasound examinations to be completed without direct expert input. We assessed the performance of our first virtual guidance module with novice ultrasound operators by performing targeted cardiac ultrasound examination in a remote desolate location in the high Canadian Arctic. The goals of this pilot study were to determine whether a software-based, virtual guidance program is a useful tool to enable novice operators to perform an ultrasound examination and to evaluate the quality of the resulting ultrasound images.

Methods

The study was reviewed and approved by the Henry Ford Health System Human Investigation Committee (Detroit, MI, USA). Participants' signed a consent form after being briefed and reading the layman's summary.

Procedure

A 15-min virtual guidance program was developed which included video clips, still images and audio instructions (Fig. 1). The guidance program demonstrated patient and operator positioning, equipment operation, and scanning techniques. The program provided a detailed, step-by-step

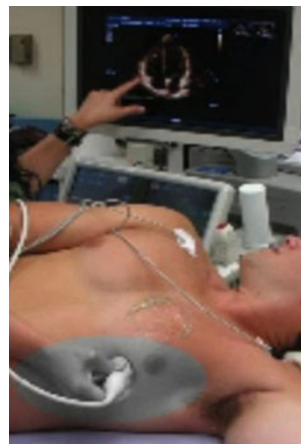


Fig. 1 The multimedia, virtual guidance program included short audio-visual segments which described the technical requirements of performing a targeted echocardiographic examination

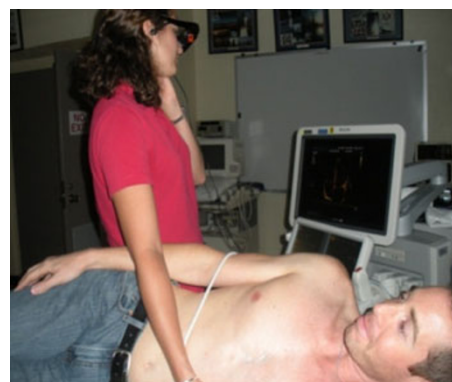


Fig. 2 The virtual guidance system was developed and tested in the Cardiovascular Lab at the Johnson Space Center in Houston, Texas

instruction for each of the required cardiac views by displaying the anticipated location of the acoustic window (probe placement site) with the corresponding reference (target) image. Suboptimal images or views from incorrect probe placement were also provided along with the probe manipulations to adjust the scanning plane to improve the image. Pilot testing of the virtual guidance program and technique was initially done using novice volunteer operators recruited by the Cardiovascular Laboratory at NASA Johnson Space Center (Fig. 2). Based upon these experiences, the final virtual guidance training protocol was established.

The video program was loaded into a commercially available portable media player (iPod Classic, Apple Inc., Cupertino, CA, USA) and viewed through a set of audio-visual glasses (Fig. 3). The player with this peripheral device provided excellent resolution (320 × 240; equivalent to a 44 in. screen viewed at 9 feet) and audio perception of the instructional material while allowing concurrent visualization of subject and ultrasound device.



Fig. 3 A virtual guidance system was created using currently available technology (an iPod and 3D video glasses, iWear IP230, Vuzix Corp, Rochester, NY, USA) to allow an ultrasound operator to view a procedural video while performing an ultrasound examination



Fig. 4 A compact, portable ultrasound system was used for the echocardiographic evaluations in the high Arctic. The unit was battery-powered to allow unencumbered scanning in the field

A battery-powered, compact ultrasound device (Zonare Medical systems, Inc., Mountain View, CA, USA) was used with a P 4-1C phased-array transducer was used for the echocardiographic examinations (Fig. 4).

The virtual guidance experiments were conducted at Resolute Bay, Canada in the high Arctic Circle. Four untrained operators without previous ultrasound experience (two males and two females, ages 25–45 years), had diverse professional backgrounds (geologist, electrical engineer, hotel manager, and medical student) each performed cardiac ultrasound on four normal, male volunteer subjects (ages 35–45 years) following informed consent.

The scanning protocol consisted of a set of standard, echocardiographic images:

1. parasternal long axis (PLAX) Two Dimensional (2D),
2. parasternal long axis (PLAX) color Doppler,
3. parasternal short axis (PSAX) at the mitral level,
4. parasternal short axis (PSAX) at the papillary muscle level,
5. apical four-chamber view 2D (Apical 4),
6. apical four-chamber view color Doppler,
7. pulsed Doppler of the left ventricular inflow (apical window).

The ultrasound images were stored digitally for subsequent blinded viewing and scoring by two qualified sonographers. The qualitative scoring system was developed for the purposes of this study consisted of three components: acoustic window (0–10 points), anatomy (0–10 points), and orientation (0–10 points). The composite scores were designated as:

- Not analyzable image (0–5 points),
- Poor image (6–10 points),
- Fair image (11–15 points),
- Good or diagnostically adequate image (16–20 points),
- Very good image (21–25 points),
- Excellent image (26–30 points).

Results

All four remote ultrasound operators were able to activate and use the ultrasound equipment, position the patient, hold the probe effectively, and obtain some cardiac images by following the virtual guidance instructions as determined by the quality of the study and post-study interviews with the participants (Fig. 5). The average number of stored images was 12 (range 9–17 images), with some duplicates; the average examination time was 27 min (range 25–30 min). All operators were able to obtain three images, which were judged to be diagnostically adequate (with a score greater than 15 points): PLAX with and without color Doppler, PSAX at the papillary muscle level and mitral level, apical four-chamber view with and without color Doppler and Mitral Valve Doppler (Table 1, Fig. 6). The most reliably acquired image for the untrained operators was the PSAX at the papillary muscle level.

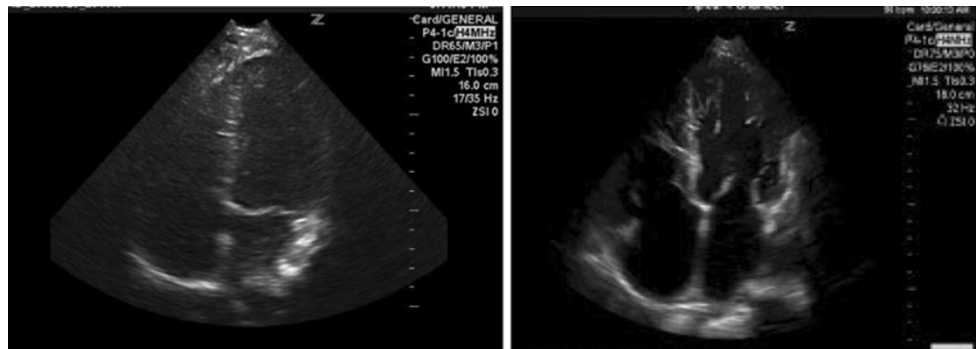


Fig. 5 The video glasses-based virtual guidance system provided direct procedural information which was followed by the non-expert operators to conduct ultrasound examinations of the heart in a remote setting

Table 1 Images, score and each of the four operator's average score for target images: parasternal long axis (PLAX) without and with color Doppler, parasternal short axis (PSAX) at two levels mitral and papillary, Apical 4 chamber without and with color Doppler, Mitral Valve (MV) Doppler flow

Target images	Operator 1	Operator 2	Operator 3	Operator 4	Total points
PLAX	–	11.5	9.5	11.5	10.8
PLAX color	24.0	23.5	24.0	10.5	20.5
PSAX mitral	–	26.0	–	11.0	18.5
PSAX papillary	25.5	17.0	24.5	16.0	20.8
Apical 4	20.0	23.0	21.0	16.0	16.25
Apical 4 color	15.0	17.5	–	14.0	15.5
MV Doppler	22.5	–	18.5	12.5	17.8
Avg. points	21.4	19.75	19.5	13.1	

Fig. 6 Representative cardiac ultrasound images (apical) from an expert and a novice operator using virtual guidance are shown. The video-based instructional program enabled non-trained personnel to perform diagnostic quality ultrasound examinations



Not all operators stored all seven required target images; each operator's final score was calculated based on the total number of images. Operator #1 obtained the highest average score (21.4 points) based on five of the seven required target images, and operator #4 obtained the lowest score (13.1 points) based on the seven images required.

All ultrasound operators reported the virtual guidance experience was constructive in their ability to perform the exam. Some suggestions for improvement in the video program included: (1) creating a chapter for each image to allow the operator to view the instruction as long as they need before proceeding to the next image, (2) maintaining the reference image in upper screen view while showing trouble shooting images in the middle of the screen, and (3) programming a short time delay with a persisting display of the target image after the instructional component is finished in order to increase image recognition.

Discussion

Point-of-care ultrasound is a valuable complement to the physical examination that greatly facilitates decision-making in a wide variety of clinical conditions. It has gained the broadest recognition in emergency medicine, owing to mounting evidence, acceptance, growing

portability and affordability of equipment, and formal training opportunities. Wider adoption of point-of-care ultrasound among non-urban health care providers is hampered by the lack of trained sonographers. The extension of ultrasound to remote or under-served environments is not progressing rapidly; novel expertise delivery approaches are being developed to maintain ad-hoc ultrasound capability and improve on-site decision-making to enhance the quality, speed, and outcome of medical care.

The ISS ultrasound system was activated in 2000, to become first-ever permanently installed imaging system in space. NASA researchers have used it not only for space physiology research, but also as a highly successful testing platform for developing and assessing various expertise delivery solutions to overcome the problem of “inexperienced operator” [8]. Autonomous performance of medical ultrasound is a current focus in space medicine. The current remote guidance methodology, complete with just-in-time training and adaptive reference tools, has been accepted by all the ISS Partners as an established and proven operational capability that decreases the likelihood of unnecessary delays in medical treatment or medical evacuations. Numerous ultrasound examinations including echocardiography have been performed on the ISS using remote ultrasound guidance during the Advanced Diagnostic Ultrasound in Microgravity (ADUM) investigations and other experiments [5–7].

Remote expert guidance works effectively in low earth orbit and likely will on lunar missions as the distance associated communications delay will be less than 2 s. The technique will not be suitable for future exploration class missions at greater distances from Earth due to significant increases in the communication delay which will exceed 30 min for a Mars mission. Real-time communication may not be readily unavailable in many terrestrial settings as well, or may be limited to voice or off-line file exchange. The prior successes in using novice ultrasound operators with remote guidance makes it worthwhile to study and characterize the “extreme” case of a completely autonomous ultrasound operator guided by a multimedia instructional program (“virtual guidance”).

This is the first description of “virtual guidance”, which incorporates elements of remote expert guidance into a platform suitable for autonomous care without direct communication between the expert and the operator. Virtual guidance replaces the remote guidance expert with a multimedia program that can be viewed, paused, rewound, and replayed while performing the examination. It is an aid to facilitate operator-dependent procedures and augments forgotten training, limited clinical expertise, or unanticipated clinical scenarios. The technique consists of a short, multimedia program which can be edited and stored on a portable device and is viewed through wearable video glasses. This ergonomic system allows the operator to view the instructional material on demand and have both hands free to conduct the ultrasound procedure. Video glasses have been used to help guide ultrasound interventions previously, however, virtual guidance combines expert instructions with the viewing device to facilitate complex examinations.

This study describes the first deployment of virtual guidance in a remote environment. It demonstrates, for the first time, that virtual guidance may be a useful technique to enable non-expert operators to conduct complex ultrasound examinations; additional studies are necessary to define the full utility of this technique. The untrained operators in this trial were able to obtain diagnostic quality echocardiographic images using a video-based, instructional program delivered just-in-time through video glasses. The remote operators were able to conduct the examinations within 30 min using virtual guidance and would have been able to electronically transmit diagnostic quality cardiac images to a remote expert for interpretation in situations where direct communication is impossible. Numerous “lessons learned” were recorded during this trial, which will improve the technique in future iterations. Suggested upgrades to the current program include incorporating picture-in-picture viewing of reference imagery within the procedure video, chaptering of key examinations, and programming redundant imagery within the

training loop to enhance image recognition. Such enhancement of the basic virtual guidance program promises substantial improvement of performance. The program could be adapted for many complex medical and non-medical procedures that require unique expertise not available at the operational site. Future enhancements may also include pathologic reference imagery or computer-assisted pattern recognition capability; emergency therapeutic techniques such as high frequency ultrasound hemostasis or image-guided nerve blocks could be considered as candidates for advanced virtual guidance modules of future autonomous medical capability systems.

Innovative caregivers have expanded the utility of ultrasound in a wide variety clinical situations and locations. Point-of-care ultrasound has been successfully performed in a number of austere medical locations including low Earth orbit, mountain peaks, polar outposts, submarines, underserved rural locations, and combat areas [4–7, 9–13]. Novel training techniques such as remote expert guidance and virtual guidance serve to enable the non-expert operator to utilize this robust, portable, and affordable technology to enhance medical diagnostic capabilities on and off the planet.

Conclusion

Virtual guidance may facilitate the performance of echocardiography by inexperienced operators. Discrete diagnostic quality echocardiographic images were obtained by the remote operators which could be used to answer clinical questions involving the heart. This small pilot study in the remote location of the high Arctic Circle suggests that virtual guidance should be explored as an effective training technique for exploration class spaceflight and for remote locations worldwide.

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Conflict of interest None.

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