Ocular Examination For Trauma; Clinical Ultrasound Aboard The International Space Station

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Background: Ultrasound imaging is a successful modality in a broad variety of diagnostic applications including trauma. Ultrasound has been shown to be accurate when performed by non-radiologist physicians; recent reports have suggested that non-physicians can perform limited ultrasound examinations. A multipurpose ultrasound system is installed on the International Space Station (ISS) as a component of the Human Research Facility (HRF). This report documents the first ocular ultrasound examination conducted in space, which demonstrated the capability to assess physiologic alterations or pathology including trauma during long-duration space flight.

Methods: An ISS crewmember with minimal sonography training was remotely guided by an imaging expert from Mission Control Center (MCC) through a comprehensive ultrasound examination of the eye. A multipurpose ultrasound imager was used in conjunction with a space-to-ground video downlink and two-way audio. Reference cards with topological reference points, hardware controls, and target images were used to facilitate the examination. Multiple views of the eye structures were obtained through a closed eyelid. Pupillary response to light was demonstrated by modifying the light exposure of the contralateral eye.

Results: A crewmember on the ISS was able to complete a comprehensive ocular examination using B- and M-mode ultrasonography with remote guidance from an expert in the MCC. Multiple anteroposterior, oblique, and coronal views of the eye clearly demonstrated the anatomic structures of both segments of the globe. The iris and pupil were readily visualized with probe manipulation. Pupillary diameter was assessed in real time in B- and M-mode displays. The anatomic detail and fidelity of ultrasound video were excellent and could be used to answer a variety of clinical and space physiologic questions.

Conclusions: A comprehensive, high-quality ultrasound examination of the eye was performed with a multipurpose imager aboard the ISS by a non-expert operator using remote guidance. Ocular ultrasound images were of diagnostic quality despite the 2-second communication latency and the unconventional setting of a weightless spacecraft environment. The remote guidance techniques developed to facilitate this successful NASA research experiment will support wider applications of ultrasound for remote medicine on Earth including the assessment of pupillary reactions in patients with severe craniofacial trauma and swelling.

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The Human Research Facility (HRF) in the International Space Station (ISS) provides a research platform to develop and test medical care strategies and procedures in anticipation of future long-duration, exploration-class missions.[1,2] There is no current or planned X-ray or CT capability on the ISS, however a space-adapted ultrasound system is available for research or medical diagnostic use.[3,4]

Numerous investigations have highlighted the accuracy of ultrasound in the detection of injuries to the chest, abdomen, musculoskeletal system, and eye.[5-9] Recent studies also have shown that non-physician operators can reliably perform a number of focused clinical ultrasound examinations to facilitate on-site diagnosis.[10] NASA experts have rated trauma and acute medical problems at the highest risk level, when weighed by their predicted incidence and the magnitude of their impact.[11-12] This report documents the first performance of a comprehensive ocular ultrasound examination by a minimally trained astronaut crewmember on the ISS using remote guidance and on-board reference cards.

METHODS

The studies reported herein were approved by the Henry Ford Hospital Investigation Review Board and the NASA Johnson Space Center Committee for the Protection of Human Subjects. The Advanced Diagnostic Ultrasound in Microgravity (ADUM) in-flight research investigation evaluates the ability of nonphysician crewmembers to perform various ultrasound examinations while guided in real time. Long-duration ISS crewmembers receive approximately 3 hours of ultrasound training at the Johnson Space Center, including an overview of the hardware and the principles of ultrasound. The Increment-10 crew also had 2 hours of hands-on instruction in clinical ultrasound specific to the ADUM experiments, including ocular ultrasound, approximately 4 months before

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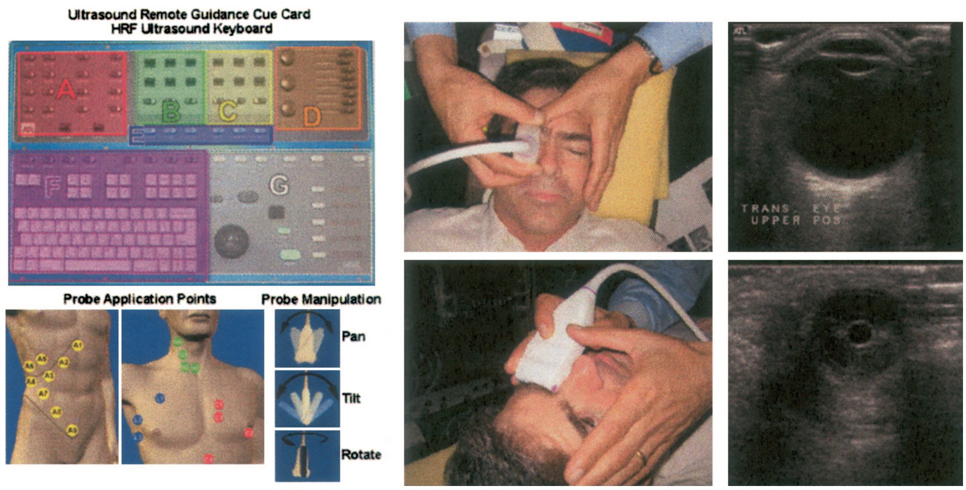

FIG 1. *A reference "cue card" was developed for use with input from astronaut users to facilitate clinical ultrasound examinations on the ISS. The card contains information on equipment controls, probe placement, representative images, and probe manipulation.*

the flight. During flight, the crew reviewed a 1-hour "On-Board Proficiency Enhancer" (OPE) computer program within a week of the ultrasound examination. OPE is a multimedia educational program that reviews ultrasound basics, remote guidance terminology, relevant human anatomy, and tips for performing better-quality ultrasound examinations. A small reference card ("cue card"), containing layout coding for equipment controls and probe placement points, was uplinked for use during the guided imaging process (Fig. 1).

The ISS ocular ultrasound examination was performed on a space-adapted version of the HDI-5000 System (Philips Medical Systems, Bothell, WA), which was configured with a broadband 5–12 MHz linear probe. The output of the system was displayed on an on-board monitor and also was transmitted live via a satellite link to the MCC in Houston, TX, with a 1.8 second delay. Real-time secure audio link was used between Mission Control at the Johnson Space Center in Houston and the ultrasound operator astronaut on the ISS. High-resolution images were stored locally on the ultrasound and transmitted after examination for final review and analysis.

The astronaut operator was securely restrained by foot straps and hand positioning before the ultrasound examination. The subject was restrained supine on a crew medical restraint system using straps to maintain a stable position in microgravity and to allow precise positioning of the probe on the eyelid to avoid injury (Fig. 2). A radiologist with extensive hands-on sonographic and remote guidance experience continuously viewed the live ultrasound image and verbally instructed the crewmember to adjust the system settings and modify probe placement. The ocular examination was initiated by placing the linear probe in a sagittal orientation over closed eyelids. The subject was instructed to fix his gaze on a remote object and keep his contra-lateral eye open. The probe was manipulated to the sagittal antero-posterior plane through the middle of the globe, resolving the anterior chamber and the lens. This initial target image was used to estimate the amount of pressure exerted by the probe as shown by flattening of the corneal curvature; pressure was regulated to maintain corneal convexity. The probe was then slowly rotated 90 degrees successively in both directions, keeping the anterior chamber in view, to obtain a set of antero-posterior views in the entire 360-degree rotational range.

A coronal view of the globe at the iris level was obtained by having the subject direct his gaze in a cephalad direction and placing the probe over the edge of the zygomatic arch in transverse orientation. The probe was slowly translated to abut the lower eyelid and tilted to achieve coronal planes in relation to the globe and obtain a view of the iris. The subject was instructed to intermittently cover his contra-lateral eye with his hand to demonstrate pupillary response to changing light conditions; M-mode ultrasound was used to document

FIG 2. *Cosmonaut Salizhan Sharpiov is seen in the Human Research Facility on the International Space Station performing an ocular ultrasound examination on Astronaut Leroy Chiao. The crew-members used a restraint system and foot-straps to stabilize the "patient" and operator during the examination.*

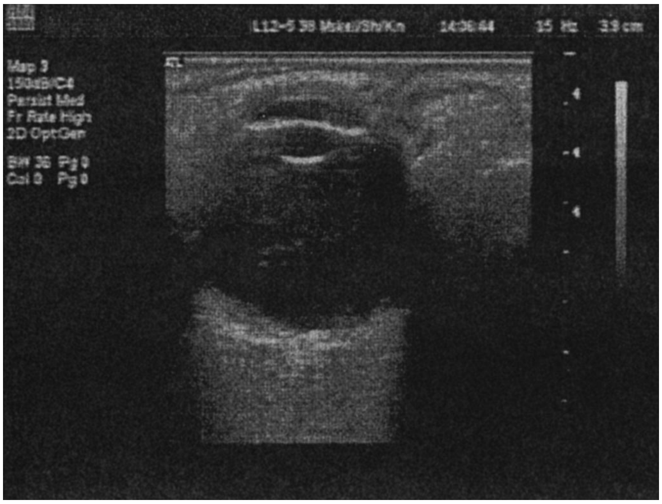

FIG 3. *The ultrasound probe was initially placed in a transverse position over the mid portion of the upper and lower eyelid. The probe was finely manipulated until a transverse image of the lens and ocular structures were identified. Limited probe pressure on the eye is confirmed by the round shape of the vitreous humor. The lens, aqueous and vitreous humor, and retina can be seen in this image.*

the pupillary reaction, quantify the change in diameter, and gauge the temporal response.

RESULTS

There was a 1.8 second satellite transmission delay for both video and audio, which did not impact the ultrasound examination. The subject reported no discomfort either during or after the examination, which was completed in approximately 10 minutes.

A combination of remote guidance commands for probe placement and manipulation, with reference to the cue card, allowed a series of high quality antero-posterior images of the eye to be obtained, representing the entire volume of both the anterior and the posterior segments of the globe (Fig. 3).

The iris/pupil was imaged with a transverse, cranially oriented probe position through the inferior eyelid. Pupillary response was easily demonstrated by covering the contralateral eye (Fig. 4). B-mode display of the pupillary opening was used to confirm and quantify response to light. A change in papillary diameter of approximately 30% was obvious in both B- and M-mode displays (Fig. 5).

DISCUSSION

In a consensus conference of health care experts, the NASA Critical Path Roadmap Project rated trauma and acute medical illness events at the highest level of risk in terms of predicted incidence versus the potential impact on mission and crew health.[13] Ultrasound is currently used in most trauma centers as the first-line diagnostic procedure in abdominal trauma, and has been demonstrated as accurate and sensitive even when performed by nonradiologists.[7-10] The expanded use of ultrasound to provide diagnostic information on additional acute clinical conditions has been investigated by NASA researchers, including chest and abdominal trauma, sinus or dental infection, and musculoskeletal injury.[6,8,14-18]Many of these ultrasound applications have been reproduced by non-expert operators; their findings suggest that ultrasound may be expanded to uses in remote locations without a high level of on-site expertise.

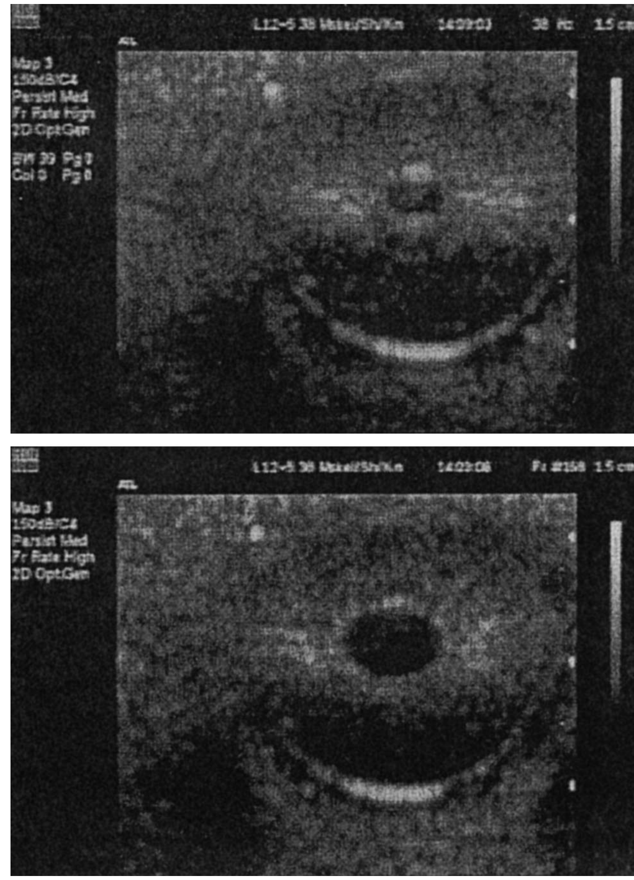

FIG 4. *The pupil is evident in this ultrasound image through the inferior eyelid. Pupillary reaction to light was readily apparent when the crewmember exposed the contra lateral eye to light.*

The feasibility of ultrasonic imaging in human space flight has been investigated in preliminary experiments on both U.S. and Russian spacecraft.[19-22] NASA researchers have demonstrated the utility of diagnostic ultrasound in abdominal and thoracic trauma in microgravity experiments using animal models during parabolic flight on KC-135 aircraft.[16-18,23] These investigations have verified that the sensitivity and specificity of ultrasound is not degraded in microgravity, and may even be enhanced in certain circumstances. More recently, a focused abdominal survey for trauma (FAST) examination and a shoulder musculoskeletal examination have been completed on the International Space Station by nonphysician crewmembers using remote guidance.[14,15] Both of these ultrasound investigations pro-

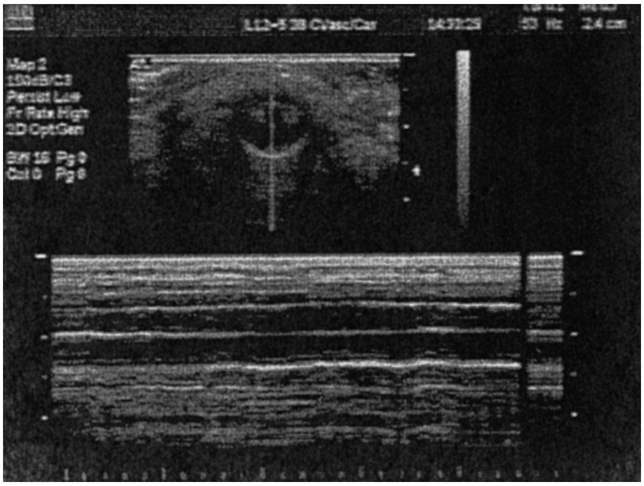

FIG 5. *M-mode ultrasonography was demonstrated as a tool to quantify the time course and magnitude of pupillary response to light. This technique provides a methodology to measure pupillary reaction to light, which may occur due to changes in the central or autonomic nervous system.*

vided diagnostic quality images to the team in the MCC, which could have been used to coordinate on-orbit treatment or evacuation decisions.

Ultrasound has practical applications in the field of ophthalmology including biometry to measure intraocular distances, bio-microscopy with ultra-high-frequency probes, and general purpose scanning.[9,24] Evaluation of the eye is an important component of a physical examination in patients with trauma to the head or face; however, it can be challenging when significant orbital or facial swelling is present. The ultrasound technique described herein is performed through a closed eyelid, therefore it can be used on patients with significant facial swelling when it is difficult to open the eyelid to evaluate the pupil.

The ultrasound examination in this experiment could be used to exclude ocular pathology such as globe disruption, lens dislocation, ocular foreign body, retinal/choroidal detachment, or occlusion of the retinal artery. This report also demonstrates that quantification of pupillary light reflex can be done with B- and M- mode ultrasonography, which could be used to gauge pupillary reaction times in patients with central nervous system injuries or alterations in the autonomic nervous system.

The recent experience in clinical ultrasound aboard the ISS supports the hypothesis that a nonphysician crewmember with modest training can perform complex, diagnostic-quality examinations when remotely directed by a ground-based expert. The images acquired by the astronaut in this study were of excellent content and quality and, in a "real" trauma scenario, would have provided essential information to guide clinical decision-making. No discernible differences were noted between the ocular examination performed on orbit and those performed by an expert sonographer on the ground during the astronaut baseline examination when evaluated by the radiologist/ultrasonographer or research team involved in this trial.

This initial ultrasound experience suggests that limited training, combined with directed remote guidance, provides an effective paradigm for performing complex imaging tasks in special circumstances. The ultrasound examination was conducted using limited bandwidth, which would most likely be the case in most terrestrial situations including trauma applications.

The unique constraints imposed by the space environment require the development of novel diagnostic and therapeutic strategies.[9] The expanded use of diagnostic ultrasound is advantageous since it is readily available (hand-held portable devices) and does not expose the patient to ionizing radiation. The remotely guided ultrasound concept, with astronauts in the space program or comparably trained first responders as operators, is a significant, clinically relevant advancement in space medicine with profound ramifications for terrestrial medicine and trauma care.

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