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ORIGINAL ARTICLE

Extreme musculo-skeletal ultrasound: training of non-physicians in the Arctic Circle

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Abstract

Objective The purpose of this study was to compare if non-physician, inexperienced ultrasound subjects can take quality diagnostic images after watching a brief educational video and using reference cue cards (autonomous group) versus taking ultrasound images with expert guidance using a satellite connection.

Methods Six non-medical, inexperienced ultrasound subjects from a rural area (Arctic Circle) obtained ultrasound images of target anatomic regions using a portable ultrasound device after receiving expert-guided training or autonomous training (educational video and cue cards). Real-time expert guidance was provided using an audio-visual tele-ultrasound connection with direct ultrasound video compression which was relayed to a remote expert via a secure satellite connection. The resultant images from all studies were blindly reviewed by imaging experts for determination of diagnostic adequacy.

Results All of the examinations were completed in <15 min. The blinded expert identified 85.1% of autonomously acquired images and 86.2% of the images obtained by expert guidance to be of diagnostic quality; there was no statistical difference between the two groups ($P = 0.6653$).

Conclusion Non-physician, inexperienced subjects can quickly educate themselves to retrieve diagnostic quality ultrasound images whether they are being expert-guided or trained autonomously.

Keywords Remote care · Arctic Circle · Ultrasound

Introduction

The aboriginal communities of rural Northern Canada are faced with extremely limited access to health care. A shortage of physicians in Canada has lead to an "urban-centric" infrastructure, forcing many patients to travel great distances to obtain health care services. In 2002, the Society of Rural Physicians of Canada cited geography as a determinant of health, and partially attributed the poorer health outcomes of Northern inhabitants to the lack of health care services [1]. Undoubtedly, acute illness and injury in the high artic presents a significant challenge for both patients and health care providers.

The diagnosis of injury is a dilemma in remote areas all over the world. In developed countries, ultrasound is routinely used in the initial evaluation of trauma patients to detect hemo-peritoneum. Ultrasound is also used in the assessment of traumatic musculoskeletal injuries when radiography is not available [2–4]. The relatively low cost, ease of use, and portability of ultrasound make it an ideal diagnostic tool, not only for acute injury in developed countries, but also in remote areas without extensive medical support.

Ultrasound has historically been performed by expert operators (physician, or registered technician) with

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extensive training. Recent investigations have challenged this paradigm and have shown that non-physician, inexperienced operators can effectively obtain diagnostic quality images with guidance from an expert sonographer [5–10]. Researchers at the National Aeronautical and Space Administration (NASA) demonstrated that minimally trained astronauts on the International Space Station (ISS) could complete an ultrasound examination with real-time guidance from an expert on Earth [11–13]. The development of these innovative methods has enabled tele-sonography to be explored for terrestrial medical care.

This report investigated the ability of novice ultrasound operators to perform targeted ultrasound examinations in an austere environment to exclude injury of the musculoskeletal system using minimal training and remote expert guidance. Environmental constraints including cold weather and a lack of information access were also examined.

Materials and methods

The experiments described herein were reviewed and approved by the Henry Ford Health System Human Investigation Committee. Informed consent was obtained from all participants prior to this study. The experiments were conducted on normal subjects in an extremely remote, uninhabited location in Resolute Bay, Canada located in the high Arctic Circle.

A free standing, environmentally rugged, point of care ultrasound system was developed for use in remote environments. A battery powered, portable ultrasound system (z.one ultra, Zonare, Mountainview, CA) was used with an L14-5 linear transducer for the musculoskeletal (MSK) examinations completed in this trial. Additional batteries were available if the examinations exceeded 45 min as external power sources were not available in the field conditions. The VGA output of the ultrasound device was streamed through a video compression device (DistanceDoc, Mediphan, Ottawa, Canada) to a net book computer (ASUS EeePC, Chiba, Japan). High speed internet connectivity was established using a secure satellite modem (BGAN HNS-9201, Inmarsat Inc. Miami, FL). A video conferencing link was established between the point of care site in Resolute Bay and the remote guidance expert with extensive experience in musculoskeletal ultrasound at Henry Ford Hospital using an internet-based video conferencing program (ooVoo, NY, New York).

The examinations were randomly conducted by Inuit (native inhabitants) or other new users (non-medical, geologist scientists) under extreme environmental conditions in a field location remote from external support. There were 2 experimental novice operator groups (each with 3 members) who randomly performed MSK examinations autonomously or with remote expert guidance. The autonomous MSK examinations were performed by the operator with the aid of a short educational video and a reference image cue card (Fig. 1). Short (<2 min) instructional videos with high quality, anatomic modeling and corresponding ultrasound imaging were viewed prior to the examinations. Additionally, cue-cards with topographic and reference images were utilized in order to guide the naïve sonographer through a focused examination. MSK scans of the shoulder, ankle, forearm, and lower leg scans were completed on asymptomatic sample patients ($n = 3$). There was no instructional material covering ultrasound basics (introduction, instrumentation, physics, etc.). The MSK ultrasound examinations consisted of target anatomic images and key anatomic landmarks.

Examination	Key landmarks
Shoulder	Biceps tendon, supraspinatus, infraspinatus muscles
Elbow	Olecranon, medial and lateral epicondylar ligament
Forearm	Short and long axis views of radius and ulna
Foreleg	Short and long axis views of the tibia and fibula
Ankle	Achilles tendon long axis, deltoid ligament long axis

The remote expert guidance group received verbal targeted commands from the remote expert to the point of care operator. The remote guidance expert was able to view the ultrasound examination video in near real-time and converse via bi-directional audio over the internet. The expert gave verbal instructions on ultrasound machine settings, probe and subject positioning, and on obtaining optimal images by viewing the ultrasound video stream. An immediate assessment of the examination quality and completeness was determined from the video feed by the remote expert; high resolution images were stored on the ultrasound device for interpretation at a later time by blinded experts. Remote guidance sessions were limited to one anatomical region due to the significant cost of satellite bandwidth in this preliminary trial.

The operators were instructed to store the images they felt best resembled the sample images depicted on the cue-cards. The diagnostic quality of these images was later evaluated by a blinded imaging expert with extensive MSK ultrasound experience. Evaluation was limited to a simple designation of: acceptable or not acceptable (i.e. diagnostic, or non-diagnostic).

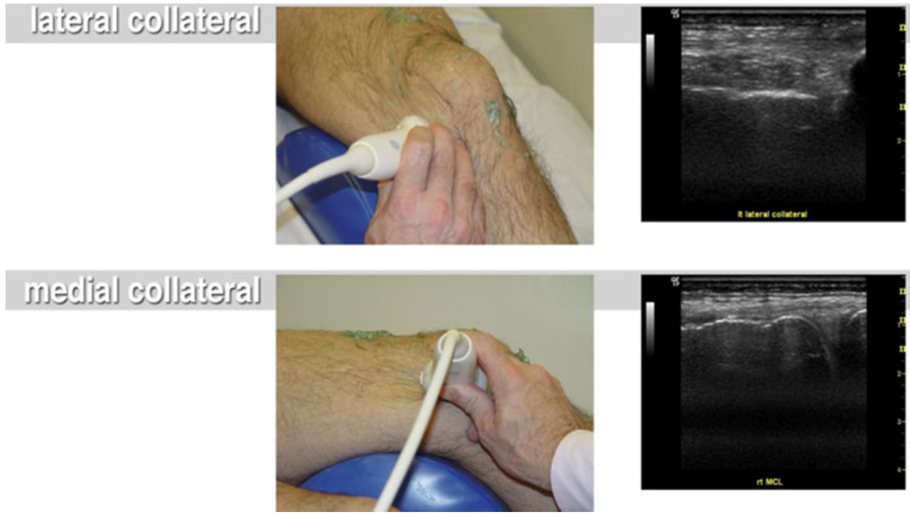

Fig. 1 A targeted "cue card" was developed for autonomous scanning which demonstrated the anatomic starting position for ultrasound probe, coupled with the anticipated ultrasound image

The data were entered into a statistical analysis program, SAS 9.2. Data were handled as dichotomized categorical data. Proportions of accurate readings of autonomous versus expert-guided were compared. Similarly a proportion of accurate, or diagnostic images, were compared across body region with the autonomous group. Chi-square and Fisher's exact test P values were obtained.

Results

The remote care device functioned without abnormality under the cold environmental conditions. Equipment setup and satellite connection time averaged 20 min prior to beginning the examinations. The non-expert users were able to perform MSK ultrasound examinations with an average ultrasound time of <10 min.

Expert-guided ultrasound ($n = 3$), and autonomous scanning ($n = 3$), were performed and various images of the following anatomic regions were acquired: shoulder, elbow, forearm, foreleg, knee, and ankle. The autonomous scanners performed shoulder, elbow, forearm, foreleg, and ankle. The expert-guided users imaged the knee only due to extreme satellite bandwidth and cost considerations.

The images acquired by expert guidance and by autonomous subjects were reviewed by a blinded expert who was only informed of the anatomic region (i.e. shoulder, knee, ankle, etc.). The criteria for determining if the image was diagnostic were based on identifying key anatomical landmarks to orient the expert. In addition, a clear view of the MSK anatomy had to be present so the expert could evaluate if there was an injury and/or abnormalities (Fig. 2, 3, 4, 5, 6, 7). The expert found 86.2% of the expert-guided ultrasound images and 85.1% of the autonomous ultrasound images to be diagnostic quality (Table 1). By Fisher's exact test there was no significant difference between the two ($P = 1$).

Fig. 2 Autonomous obtained ultrasound image of medial elbow with ulnar collateral ligament, common flexor tendon, and medial epicondyle

There were regional anatomic differences in the ability of an untrained operator to obtain diagnostic quality images. Extremity ultrasound was readily performed by all operators (Table 2). In contrast, only 50% of operators were able to adequately image the elbow in the normal subjects in this trial ($P < 0.03$ by Chi-square, $P < 0.01$ by fisher's exact when comparing elbow to all other regions).

Discussion

Providing medical care in under-served or remote areas is difficult due to limitations of skilled personnel, a lack of equipment, and environmental challenges; these same constraints are problematic for the current space program. NASA is investigating a number of novel techniques to enhance medical care capabilities in the current and future

Fig. 3 Autonomous obtained ultrasound image of musculotendinous junction of achilles tendon (long axis)

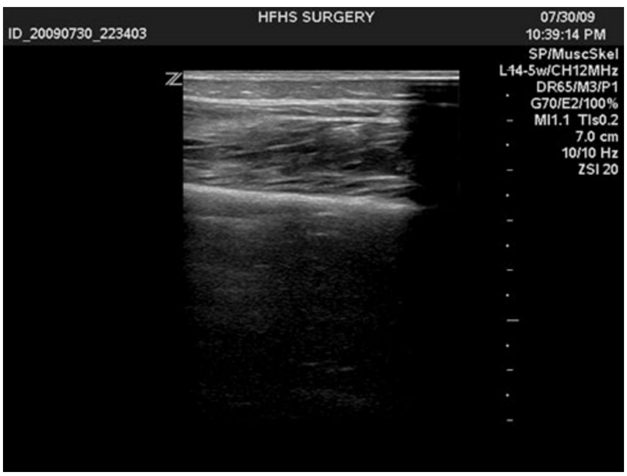

Fig. 4 Autonomous obtained ultrasound image of tibia (long axis) highlighting a muscle tear

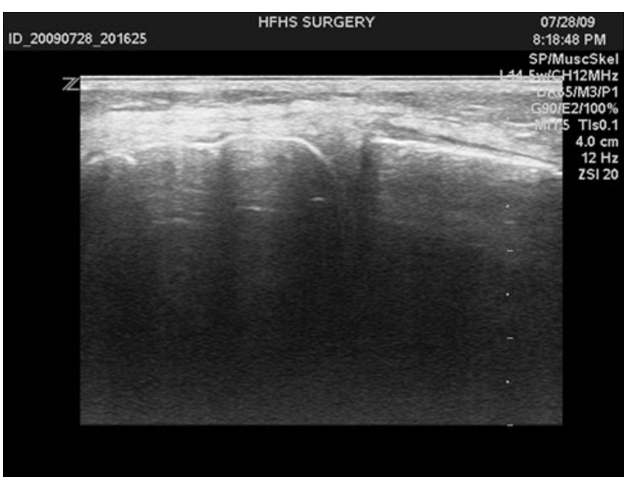

Fig. 5 Expert-guided ultrasound image of the medial meniscus with the medial collateral ligament (MCL)

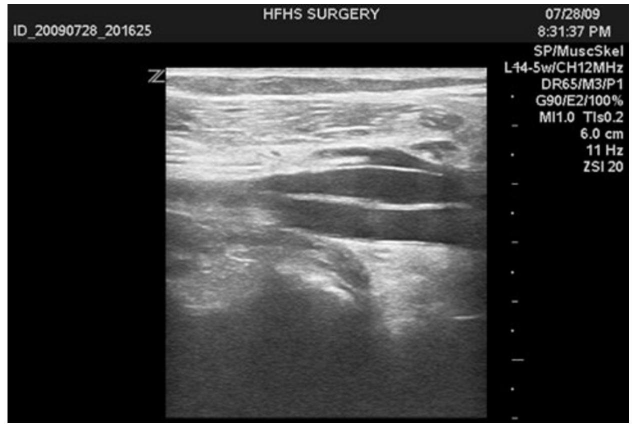

Fig. 6 Expert-guided ultrasound image of the popliteal vessels (long axis)

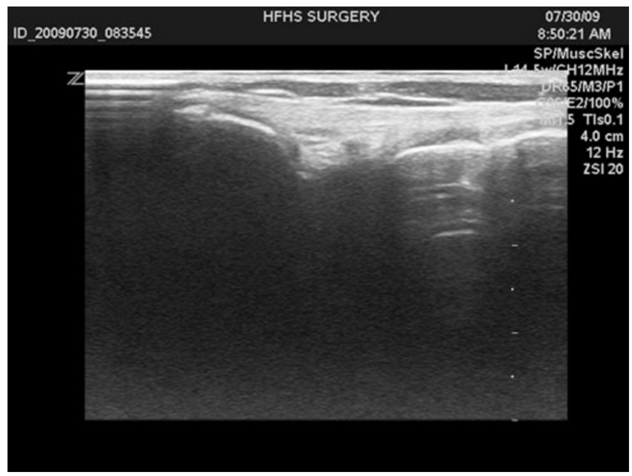

Fig. 7 Expert-guided ultrasound image of patellar tendon (long axis)

Table 1 Accuracy of expert-guided versus autonomous sonography ($P = 1$ by Fisher's exact test)

Method of ultrasound	Accuracy	
	Diagnostic/total images	Percent (%)
Expert-guided	25/29	86.2
Autonomous	40/47	85.1

space program including just-in-time educational programs, intuitive medical devices, and expanded uses for point of care ultrasound [14–17].

Ultrasound is currently used in most trauma centers as the first line diagnostic procedure in patients with abdominal trauma and has been verified as accurate and sensitive even when performed by non-radiologists [18]. Advances in ultrasound technology have led investigators to suggest expanded diagnostic applications of ultrasound to evaluate the thorax, long bones and joints, soft tissues including

Table 2 Variation in diagnostic quality images based on anatomic region (autonomous)

Anatomic region	Accuracy	
	Diagnostic/total images	Percent (%)
Shoulder	12/14	85.7
Elbow	4/8*	50
Forearm	3/3	100
Foreleg	14/14	100
Ankle	7/8	87.5

* $P = 0.029$ for entire table, $P < 0.01$ for elbow difference from other regions

odontogenic and sinus infections and evaluation of foreign bodies or trauma to the eye [8, 14].

Evidence-based trials have demonstrated the accuracy of ultrasound in a wide variety of aerospace relevant clinical conditions when performed and interpreted by experts. Recent International Space Station experiments have shown that just-in-time trained astronaut crew-members, equipped with on-board proficiency enhancement, can acquire complex, diagnostic quality ultrasound images [17]. The expansion of just-in-time ultrasound training to autonomous ultrasound operation, coupled with enhanced on-site interpretative capabilities, would significantly expand the medical diagnostic capabilities and would provide significant, clinically relevant advances in space medical capabilities with profound Earth-based ramifications.

Significant musculoskeletal degeneration occurs during long duration spaceflight. Mission specific requirements which necessitate exertion after a prolonged microgravity exposure may heighten the risk of injury during exploratory missions in the future. Significant reductions in muscle mass and strength occur during long duration spaceflight despite aggressive exercise regimens [19, 20]. The ability to longitudinally quantify decrements in muscular mass/strength during spaceflight would provide a reliable predictor to guide anticipated work requirements and scheduling to maximize crewmember performance. Several investigators have demonstrated that ultrasound can accurately identify acute bony and ligamentous injury; however, these reports do not involve large study cohorts [2–4, 14, 21, 22]. Ultrasound can also be used to determine the degree of healing of bone and degeneration. Orthopedic ultrasound appears to be a promising area of application which is currently being investigated by NASA scientists.

This is the first report comparing remote expert guidance and autonomously performed ultrasound in an austere environment. The experiments were performed in the field at Resolute Bay, Canada, high in the Arctic Circle. This environment was chosen due to its extremely remote location, and lack of electricity/connectivity as an extreme test of the point of care capabilities of portable ultrasound. A battery-powered, environmentally rugged, high fidelity ultrasound device functioned well for the imaging requirements of this trial. Phone and video-streaming connectivity was established for the remote guidance section of the trial via satellite uplink without difficulty, despite being at the extreme edge of satellite coverage. Remote connectivity was used sparingly due to the very high cost of satellite bandwidth.

Volunteer operators, without prior ultrasound experience, were able to complete ultrasound examinations with or without real-time guidance. The autonomous scans which were successfully completed suggest that targeted training algorithms may allow minimally trained operators to perform diagnostic examinations with a minimum, or no connectivity. The majority of examinations were completed successfully and yielded diagnostic quality images. Further attention to training or additional materials may be required for challenging anatomic regions such as the elbow.

This study had several limitations which should be addressed in future, more comprehensive examinations. The ultrasound examinations were conducted in asymptomatic subjects, therefore, the ability of the operator or the remote expert to diagnose pathologic conditions was not established for this protocol. This was a preliminary report due to significant environmental and financial constraints. The number of operators and subjects was not large due to challenges in recruitment due to the small population and limited time spent in the Arctic Circle. The average cost per satellite session was approximately $150 due to the large data file transmission characteristics of video transfer. The environment posed significant challenges including temperature (which reduced battery efficiency and exposed examination times), location (the extreme northern location was at the uppermost limit of satellite coverage mandating careful satellite antennae positioning), and resource constraints (external power was not always available).

This report suggests that point of care ultrasound may provide a diagnostic tool for remote or under-served regions where skilled health care professionals are scarce. Inexperienced operators were capable of performing focused ultrasound examinations and achieving targeted, diagnostic quality images autonomously or with real-time remote expert guidance. Basic, rapidly assimilated, instructional media (cue-cards and short instructional videos) provided adequate training to enable non-experts to obtain potentially important medical information using ultrasound. NASA researchers have demonstrated the utility of ultrasound in space medicine to provide timely answers for medical conditions which may occur in space. This preliminary report suggests that this technology can provide an in-expensive, deployable, and scalable diagnostic solution for a variety of health care challenges worldwide. The early diagnosis and medical management of medical problems in geographically distant locations could lessen the morbidity and mortality that disproportionately affect those living in these areas.

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Conflict of interest None.

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