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Teleultrasound in Remote and Austere Environments

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Health services in remote and austere settings are challenged by limited resources and geographic distance. Lack of investigative tools or local specialist care may impede timely diagnoses or focused treatment. Teleultrasound is an effective tool to overcome these obstacles, permitting trained experts to provide guidance to isolated environments. This paper reports on the many applications of teleultrasound and recent developments in the field.

Keywords: teleultrasound, remote, austere, mobile

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Background

The provision of global health is impeded by limited resources and geographic barriers in remote and austere environments. Despite global advances in connectivity, these populations experience higher rates of morbidity, mortality and poorer access to health services in comparison to metropolitan areas.[1] Telemedicine, defined as 'healing at a distance' aims to bridge this disparity by utilising mobile telecommunication technologies to provide health care services across geographic, social and cultural barriers.[2] Whilst the incongruence between urban and remote locations is multifactorial, the burden of inequality is greatly alleviated by access to diagnostic tools, to assist clinical decision making, counselling, intervention and triaging need for patient transfer.

Teleultrasound

Ultrasonography is an ideal solution. The World Health Organization has determined ultrasound to be an essential technology for developing countries, with access to ultrasonography designated a minimum global standard.[3] Non-invasive and without ionizing radiation, ultrasonography is highly portable, cheaper and more accessible than other diagnostic modalities.[4] Indeed, ultrasonography may be considered an extension of the physical examination, much like the stethoscope.[5] The applications for ultrasonography are myriad and their portability has seen them used in many non-hospital settings such as military deployments, onboard aircraft, and at natural disasters.[1] In most metropolitan healthcare systems, ultrasonography is performed by trained technicians with images interpreted by experts. Thus, even if ultrasonography equipment is available, in untrained hands or in the absence of professionals to interpret images, care for remote populations is still ultimately lacking.

This conundrum led to the development of 'teleultrasound', the transmittance of ultrasonographic images to experts at remote sites. In early stages, sonographic images were transmitted along telephone line internet connections.[1] Studies may be transmitted asynchronously or synchronously.[6] Asynchronous studies are characterised by obtaining ultrasonographic images, saving them onto storage and transmittance later for interpretation.[6] Proponents of asynchronous transmission suggest this modality to be superior, as resolution is lost during live transmission.[7] Limitations of asynchronous transmission are due to lack of direct interaction between the operator performing the ultrasound and the remote expert, preventing immediate supervision, with the potential loss of valuable contextual information.

Technology later expanded toward utilising wireless internet and satellite connections. As technology evolved to become more compact and portable, ultrasounds with smart phone or tablet compatibility emerged, allowing seamless integration of video conferencing, internet connectivity and scanning in a single handheld device.[8] Here, images are transmitted synchronously, or in 'real-time', with adjunctive video-conferencing software. This allows live assessment of ultrasound images, also permitting a remote expert to supervise an untrained provider in achieving the appropriate sonographic planes or implementing a procedure.[1] With synchronous transmission, real-time teleultrasound can be expanded to any remote or austere setting where there is internet or satellite connectivity for both clinical guidance and educational purposes.

Applications

Ultrasonography is a vital tool with both diagnostic and procedural capabilities and can be applied in almost any setting to all organ systems. In obstetric care, ultrasound is the diagnostic tool of choice for both metropolitan and remote settings. The lack of ionizing radiation is safe to foetuses, and suitable for evaluating intrauterine growth, pregnancy complications or developmental abnormalities.[9] Studies have demonstrated close correlation between local and remote diagnosis in obstetric examinations. Unfortunately, many pregnant women are not near specialist foetal ultrasound services. Rabie et al. evaluated teleultrasound in the diagnosis of foetal structural abnormalities, finding similar sensitivity and specificity to on-site ultrasound.[10] In Queensland Australia, Chan et al. established a foetal tele-ultrasound service, linking patients in Townsville to subspecialists in the capital city Brisbane, located 1500 kilometers away. In their series of 90 teleultrasound scans, local providers diagnosed all anomalies and significant diagnoses, and reported that one third of patients avoided costly transfer for further care, due to teleultrasound.[9]

Trauma in remote areas results in morbidity and mortality two to threefold.[1] Rapid diagnosis is imperative for dictating the treatment algorithm. Ultrasound can be used to quickly assess patients for peritoneal, pleural or pericardial effusion or tamponade using a Focused Assessment with Sonography for Trauma (FAST) scan.[11] Similarly, ultrasound can be extended to assess pneumothorax, pneumonia, intraperitoneal free gas, maxillofacial fractures or even raised intracranial pressures via optic sheath examination.[4] Results have significant logistic and cost ramifications in remote or austere environments; a positive scan might pre-empt a laparotomy or urgent transfer to tertiary service, whereas a negative scan provides reassurance and can prevent a costly unnecessary transfer. In Calgary, Canada, Dyer et al. created a tele-link between a remote health care service and a tertiary trauma centre. Using synchronous ultrasound and video livestreaming, FAST scans were observed or supervised, facilitating algorithmic treatment as well as providing clear educational benefits.[12]

Education

Teleultrasound demonstrates clear educational utility in its supervisory capacity for nontrained remote providers. Remote mentoring has been demonstrated to be effective for non-expert physicians but also non-physician professionals such as paramedics and even astronauts. In one study, naive ultrasound paramedics assisted remotely by emergency physicians were able to achieve adequate FAST views in less than five minutes.[13] Similarly, a study of 21 non-medical undergraduate students supervised by a remote expert were able to obtain sonographic planes to assess for pneumothorax, cardiac function and abdominal free fluid, with blinded and non-blinded interpreters achieving 100% agreement on views.[14]

The potential for teleultrasound are apparent in its various applications by the National Aeronautics and Space Administration (NASA) in space, the ultimate austere environment. On the International Space Station (ISS), nonphysician astronauts have been able to complete comprehensive ocular examinations using ultrasonography under remote supervision, obtaining excellent anatomic detail and fidelity.[15] Similarly, aboard the ISS, teleultrasound has been used to perform genitourinary scans, FAST scans in trauma, and even to visualize nitrogen bubbles to evaluate decompression sickness.[4,16,17] Whilst teleultrasound has clear utility in the evaluation of real-time clinical problems, it is evident that it is also an excellent educational tool to provide training to providers, distant from traditional training facilities. Various suggestions regarding optimum duration have been proposed; however, it is likely that almost anyone can perform teleultrasound with minimal training provided they are motivated and attentive.[1]

Furthermore, with smartphone or tablet 'app-based' ultrasound and integrated internet connectivity, collaboration with other health professionals is enhanced. Ultrasound results can be transmitted via email, shared to a network for dissemination, or saved to the device for later review.

Smart phone and tablet handheld ultrasound devices

The merging of mobile technology and ultrasonography resulted in the production of third generation handheld ultrasound devices. These are characterised by smartphone and tablet-based platforms utilising 'apps' (mobile applications). These ultrasound units consist only of the ultrasound probe connected to a smart phone or tablet via a cable, with images appearing on the smart device's native display. Here, maximum portability is achieved, the ultrasound easily transportable in a bag or clothes pocket. These ultrasound devices offer integrated synchronous transmittance, including inbuilt video livestreaming, using the native smart device's camera. Gain, depth, power and colour can all be customized by touching the screen of the mobile or tablet. Furthermore, probes can be interchanged to perform any ultrasound application such as lung, abdomen, obstetrics/ gynaecology, FAST, soft tissue or vascular examinations.[8]

Several third-generation handheld devices exist currently. The Phillips Lumify permits colour Doppler, M-Mode, advanced XRES and multivariate harmonic imaging and SonoCT. Its 'Reacts' integrated videoconferencing technology permits multiple simultaneous audio-visual inputs: the ultrasonographic images, video from the smart device's camera so the observer can guide probe placement, and also video from the observer transmitted to the local provider.[18] Another recent addition to the market is the Butterfly IQ ultrasound. This features 'Butterfly Cloud' an online sharing system and is affordable, priced under \$2000 USD, whereas most standard portable ultrasound machines are in excess of \$10000 USD.[19, 20]

Successful clinical application of the Phillips Lumify ultrasound has been reported as an acceptable alternative to traditional high-end ultrasound devices. In a study of 56 plastics surgery patients, Miller et al. used the Phillips Lumify ultrasound to successfully locate dominant perforator vessels for perforator flap reconstruction, facilitate transversus abdominis plane anaesthetic blocks in patients undergoing abdominal reconstruction, and to identify the superficial fascial system in body contouring patients.[21] In another study, twenty radiology trainees used a Phillips Lumify ultrasound attached to a Samsung Galaxy S2 tablet to evaluate 10 wrist structures and completed a Likert scale-based, pre- and post-test survey, with 3 days of independent practice in between. Value as a learning tool was evident by greatly improved pre-test and post-test mean scores (2.5 ± 2.16 vs 9.85 ± 0.37, $p<0.001$). Trainees reported that these devices could enhance their ability to perform musculoskeletal ultrasound and ultrasound-guided interventional skills.

An inevitable limitation of portability is battery life, particularly in austere environments. However, the experience of Nolting et al. who charged a Lumify ultrasound exclusively with a solar panel, whilst visiting communities trekking through the Himalayas, demonstrates that smart handheld ultrasound devices are effective and feasible for even the most austere environments.[22] Given their affordability, portability and inherent advantages with internet connectivity and videoconferencing, smart phone compatible ultrasound devices represent an essential tool in minimising healthcare disparities.

Robotic Teleultrasound

Robotic guided ultrasonography has emerged as an alternative to remote supervised sonography. A remote expert manipulates a master system whose movements are reproduced by a robotic arm equipped with an ultrasound probe. Haptic technologies are also integrated to provide tactile feedback.[23]. NASA's Extreme Environment Mission Operations has used robotic systems in underwater habitat 3000 kilometers away to perform simulations such as ultrasound guided needle puncture.[24] Although expensive and used predominantly in research settings, this technology represents a novel diagnostic and treatment method for the future.

Conclusion

Teleultrasound is a quintessential adjunct in the provision of healthcare to remote and austere environments. As communities become more connected, teleultrasound embodies a vehicle for sharing knowledge and expertise to communities with limited resources or specialist providers. Synchronous transmission of sonographic images expands the scope of care. In the absence of providers trained in sonographic interpretation, images can be transmitted in real time for immediate assessment and clinical supervision by remote experts. Similarly, in austere locations where medical care is provided by nonphysicians, studies demonstrate that via teleultrasound, standards of treatment comparable to urban healthcare systems can be provided. In cases of trauma when rapid diagnosis is necessary, teleultrasound embodies an invaluable adjunct in clinical assessment or determining need for patient transfer.

Just as provision of timely care is quintessential to acceptable healthcare, the education and training of remote and austere health services is vital to closing global inequalities. Teleultrasound represents a suitable educational modality, in which local providers can receive remote supervision and teaching from expert providers. Global healthcare is tasked with disseminating appropriate resources to the furthest corners of the world. Novel technologies continue to cultivate this evolving field. Recent development of mobile portable ultrasound devices with synchronous transmission capabilities, represent the ultimate platform for providing this technology to remote and austere environments.

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