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● *Review*

ULTRASOUND FOR HIGH ALTITUDE RESEARCH

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Abstract—This review describes ultrasound techniques of potential use to high altitude researchers and discusses technical issues related to using ultrasound for high altitude research. Ultrasound allows portable, noninvasive evaluation of many physiologic parameters of interest to high altitude researchers. We discuss techniques that have been extensively used and emerging techniques that can be used to assess parameters of particular interest to high altitude researchers. We do not provide a definitive description of all ultrasound scanning methods but references to instructive sources are included. Potential drawbacks of ultrasound use, such as the need for sometimes extensive training and the potential for interobserver variation, are discussed and strategies for mitigating these are suggested. This review is meant to encourage other high altitude researchers to consider using ultrasound, either as a primary investigative modality or as an adjunct for monitoring parameters of interest in studies of physiology, altitude illness, or therapeutics. (E-mail: pfagenholz@partners.org) © 2012 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasonography, Altitude sickness, Mountaineering, Biomedical research.**

INTRODUCTION

High altitude is generally considered to begin between 1500 m and 2500 m above sea level. By convention, altitudes between 1500 m and 3500 m are considered “high altitude”, from 3500 m to 5500 m is considered “very high altitude”, and above 5500 m is considered “extreme altitude” (Dietz 2006). An estimated 140 million people live above 2500 m worldwide and millions more visit high altitude annually (Penaloza and Arias-Stella 2007; Hackett and Roach 2001). Different high altitude populations around the globe have developed a variety of genetic adaptations to living at high altitude (Yi et al. 2010). Individual high altitude residents can exhibit discrete syndromes of high altitude illness such as chronic mountain sickness, which is characterized by polycythemia, pulmonary hypertension and right heart failure (Penaloza and Arias-Stella 2007). Visitors to high altitude undergo a variety of acute and long-term physiologic changes. Three clinical syndromes–acute mountain sickness (AMS), high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE)–comprise the primary manifestations of acute altitude illness (Hackett and Roach 2001). Given the large numbers of people exposed to high altitude both acutely and chronically, understanding the physiologic changes underlying adaptation to altitude and high altitude illness is an important objective of much biomedical research. All cited studies obtained informed consent from study participants and an appropriate ethics committee or institutional review board (IRB). This article describes ultrasound techniques of potential use to high altitude researchers and discusses basic technical issues related to selecting and using an ultrasound machine for high altitude research. We focus on both techniques that have been extensively used and emerging techniques that assess parameters of particular interest to high altitude researchers, such as pulmonary edema and intracranial pressure (ICP).

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ADVANTAGES AND DISADVANTAGES OF ULTRASOUND FOR HIGH ALTITUDE RESEARCH

Ultrasound offers a number of advantages over other forms of imaging or physiologic monitoring, but it also has several limitations.

Glossary of Abbreviations

AMS – acute mountain sickness
CBF – cerebral blood flow
CT – computed tomography
DVT – deep venous thrombosis
HACE – high altitude cerebral edema
HAPE – high altitude pulmonary edema
ICP – intracranial pressure
IRB - Institutional Review Board
IVC – inferior vena cava
MRI – magnetic resonance imaging
ONSD – optic nerve sheath diameter
ONSU – optic nerve sheath ultrasonography
PFO – patent foramen ovale
sPAP – systolic pulmonary artery pressure
TEE – transesophageal echocardiography
USB – universal serial bus

Advantages

Portability. Much modern ultrasound equipment can be readily carried by hand. Compared with much of the experimental apparatus frequently employed for high altitude research, including conventional radiography, computed tomography (CT) and magnetic resonance imaging (MRI), ultrasound machines are much smaller and more portable. While these other modalities may be used in high altitude population centers, few exist at very high or extreme altitude. Most studies utilizing CT or MRI use normobaric hypoxia since this is simpler to administer to patients undergoing these types of imaging than hypobaric hypoxia (Kallenberg et al. 2007). Alternatively, data can be gathered after return from the high altitude environment, which imposes major limitations (Hackett et al. 1998; Wilson and Milledge 2008). Even full sized ultrasound machines (which are rarely required) can be easily transported to road accessible field sites or to hypobaric chambers, which may not be in close proximity to facilities with CT or MRI.

Currently, small lap-top sized machines are now comparable to many older, larger machines for most applications. Since these portable machines are typically capable of running for several hours on rechargeable batteries, they can easily be transported to and operated at remote study sites. Even if study sites lack a power source, the machines' power demands are such that they can often be met using small portable photovoltaic arrays that would be grossly inadequate for other imaging modalities. A portable ultrasound set-up with batteries, power source, a laptop computer for image storage and backup, and enough ultrasound gel for a sizeable study can reasonably be expected to weigh around 15 kg and can be carried even to remote locations by a single investigator.

As the trend toward miniaturization continues, hardware options for the investigator seeking highly portable equipment have proliferated. Companies have produced ultrasound machines that serve as attachments to proprietary laptop computers (Terason, Burlington, MA, USA), or can attach to standard laptops via a universal serial bus (USB) port (Accutome, Malvern, PA, USA; Interson, Pleasanton, CA, USA). One system (Mobisante, Redmond, WA, USA) serves as a modular attachment to cellphones. These systems can further reduce the number of separate pieces of equipment necessary, the size of the equipment and the total power demands. Integral handheld ultrasound devices with many (though not all) of the features required for the techniques listed below are now available from multiple manufacturers. It is likely that these devices will become increasingly sophisticated in the coming years. Lastly, for all portable ultrasound machines data is acquired on site in real time with no delay required for processing.

Safety. Diagnostic ultrasound has few known risks (Fowlkes and Holland 1998; Fowlkes et al. 2008). In high altitude research, the replacement of invasive pulmonary arterial catheterization by transthoracic echocardiography is an example of a potentially risky, invasive research technique being replaced by an essentially risk-free noninvasive ultrasound technique (Allemann et al. 2000). The safe, noninvasive and painless nature of ultrasound compared with other research and monitoring techniques aids recruitment by making participation more attractive to potential subjects. Additionally, the United States Department of Health and Human Services' Office of Human Research Protections specifically identifies ultrasound, Doppler measurements and echocardiography as research methodologies eligible for expedited IRB review, potentially shortening the time between the conception and execution of studies (Federal Register 2008). Because ultrasound itself does not significantly impact subjects or other experimental manipulations, ultrasonographic monitoring can easily be added to other experimental protocols for purposes of collecting additional relevant data (such as monitoring additional parameters of potential interest during a drug trial) or conducting a separate parallel study. Since ultrasound does not employ ionizing radiation, there is no known additive risk of repeated ultrasound exposures, allowing accumulation of multiple data points without endangering subjects.

Versatility. A single ultrasound machine and ultrasonographer (with appropriate training) can monitor a wide range of parameters, as described below. Since multiple parameters may be assayed using ultrasound incurring no more cost to researchers or risk to the subjects than if a single measurement were taken, the versatility of