Motorized 3D Ultrasound and Jugular Vein Dimension Measurement on the International Space Station

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BACKGROUND: Internal jugular vein (IJV) congestion occurs during spaceflight. Historically, IJV distension on the International Space Station (ISS) has been quantified using single slice cross-sectional images from conventional 2D ultrasound with remote guidance. Importantly, the IJV is an irregular shape and highly compressible. Consequently, conventional imaging is susceptible to poor reproducibility due to inconsistent positioning, insonation angle, and hold-down pressure, especially when controlled by novice sonographers (i.e., astronauts). Recently, a motorized 3D ultrasound was launched to the ISS that mitigates angulation errors and has a larger design, allowing for more consistent hold-down pressure and positioning. This short communication compares IJV congestion measured with 2D vs. 3D methods during spaceflight.

METHODS: IJV was measured prior to and following a 4-h venoconstrictive thigh cuff countermeasure. Data were acquired from three astronauts approximately halfway through their 6-mo missions.

RESULTS: The 2D and 3D ultrasound results were not congruent in all astronauts. 3D ultrasound confirmed that the countermeasure reduced IJV volume in three astronauts by approximately 35%, whereas 2D data were more equivocal. These results indicate that 3D ultrasound provides less error-prone quantitative data.

DISCUSSION: These data are the first to compare 2D and 3D methods during spaceflight in the same participants by using a known countermeasure that reduces IJV congestion. The current results demonstrate that 3D ultrasound should be the preferred imaging method when trying to measure venous congestion in the IJV, and that 2D ultrasound results should be interpreted with caution.

KEYWORDS: spaceflight, astronaut, vein compliance, vein volume, countermeasure, occlusive thigh cuffs.

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Venous ultrasound is a tool that has become high priority for spaceflight health research following the emergence of thrombosis[6] and spaceflight neuro-ocular syndrome[7] as major health risks. Venous congestion, caused by the cephalad fluid shift that occurs in microgravity, is posited to play a role in the development of both conditions. Venoconstrictive thigh cuffs (e.g., Russian Braslets) have been proposed as a possible countermeasure to combat this fluid shift by restricting venous outflow from the lower limbs.[3–5]

Traditional 2D ultrasound can be used to measure the internal jugular vein (IJV) cross-sectional area (CSA) at either a single location on the neck, or continuously between the clavicle and the mandible (**Fig. 1**, top left panel). As the IJV CSA is not uniform along its entire length,[8] the continuous method can provide a more representative view of venous distension. Continuous imaging requires manual movement of the probe along the length of the IJV, introducing potential errors which can lead to invalid measurements and poor reproducibility due to variation in insonation angle, inconsistent landmarking, and variation in hold-down pressure that results in partial or total collapse of the IJV. These sources of error can be minimized by having an experienced sonographer controlling the ultrasound

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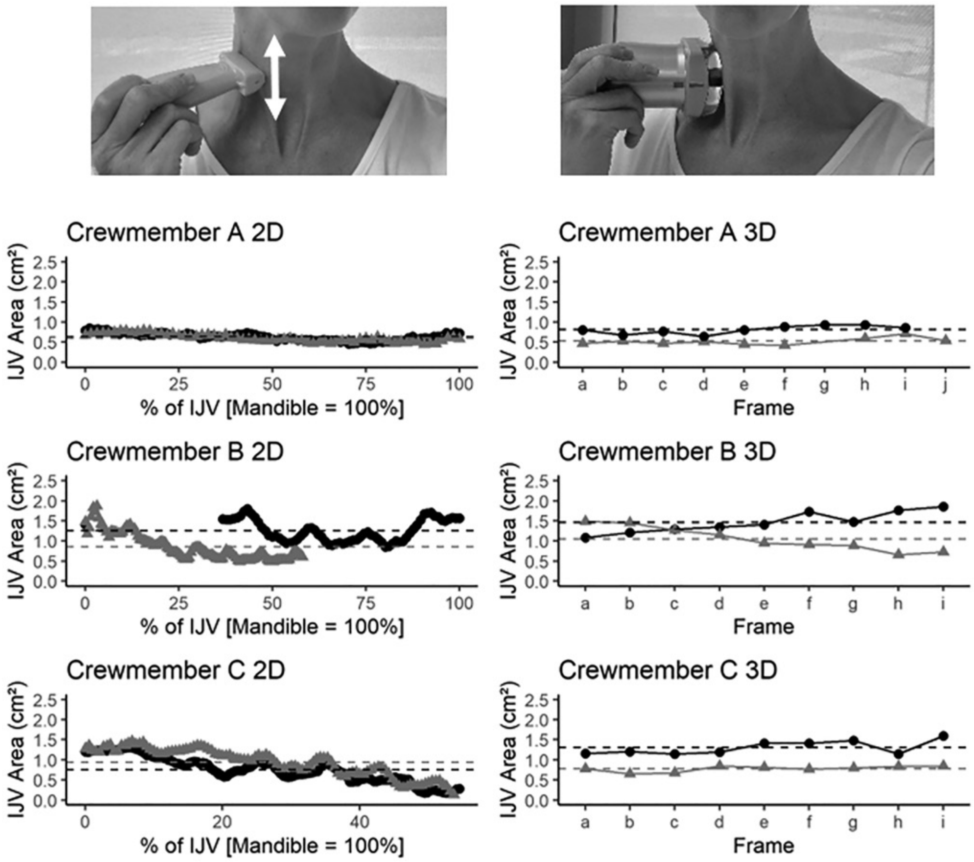

Fig. 1. Images of a participant holding the 2D ultrasound (left) and the motorized 3D ultrasound probe (right) over the right internal jugular vein (IJV). The 2D probe is manually moved up the neck to acquire images from the clavicle to the mandible; the 3D probe is motorized and the head automatically moves at a constant speed over the length of the probe head, which is approximately 3.6 cm. IJV cross-sectional area is reported for baseline (black) and, after 4 h of thigh cuff inflation (gray), by the two methods. Unreliable imaging prevented quantification of area (2D method) along the entire length of the IJV for Crewmember B.

probe, but, on the International Space Station (ISS), inexperienced crew are normally directed by remote guidance.

Motorized 3D ultrasound has several advantages over 2D. First, the probe head is large (4.5 × 5 cm vs. the 4.5 × 0.5 cm linear probe), typically covering over half the length of the neck (Fig. 1, top right panel). This allows the probe to be positioned against the clavicle and trachea consistently during repeat measures. Second, the scan speed (for sequential images) is programmed to remain constant, covering 3.6 cm in 4 s, with insonation angles corrected automatically. Third, the hold-down pressure along the length of the neck can be minimized, since the surface area in contact with the skin is large and maintained by gel (or water on ISS) across the surface area of the motorized probe front head. The ultrasound scan head moves within the front head, allowing the probe casing to maintain fixed contact with collarbone and trachea.

Imaging with motorized 3D ultrasound has been used previously during dry immersion, which induced a significant cephalad fluid shift. After 2 h, 3D ultrasound indicated that IJV volume was increased in groups with and without thigh cuffs, but the change was attenuated in the group wearing cuffs.[1,2] To date, 3D ultrasound has not been used to quantify IJV distension with and without thigh-cuffs during spaceflight.

This brief report describes the results of 2D and 3D imaging acquired via self-scan by three crewmembers who wore thigh cuffs for 4 h at the midpoint of their 6-mo mission on ISS. Images from 2D and 3D ultrasound of the IJV were collected prior to donning thigh cuffs and after having worn the cuffs for 4 h. The images were self-acquired by crewmembers who were relatively inexperienced sonographers. Each crewmember was voice-guided remotely by an experienced sonographer on Earth, with the assistance of near real-time video feeds. The objective was primarily methodological: to compare IJV volume obtained using 2D and 3D methods by a relative novice, done both at rest and after an intervention that was expected to reduce IJV volume. Secondarily, the objective was to investigate the overall ability of thigh cuffs to reduce cephalad venous congestion during spaceflight by quantifying the changes to IJV distension. We hypothesized that the 3D method would show a change in volume more consistently than 2D, and, secondarily, that IJV distension in this small group of astronauts on ISS would be reduced after 4 h of thigh cuff wear.

METHODS

Data were collected as part of the Canadian Space Agency Vascular Echo experiment. The protocol was approved by the University of Waterloo Office of Research Ethics, Johnson Space Center Committee for the Protection of Human Subjects, NASA Human Research Medical Review Board, European Space Agency Medical Review Board, and Japanese Space Agency Research Ethics Board (NASA IRB Pro1222) in accordance with the Declaration of Helsinki. Written informed consent was collected and session constraints were: no caffeine, blood pressure, allergy, or acid reflux medications; no decongestants, sleeping pills, central nervous system stimulants, or nonsteroidal anti-inflammatories for 24 h prior to testing; and no exercise on the day of testing and 2 h post-prandial.

Subjects

Three astronauts (1 woman, 2 men; height = 180 ± 2 cm, weight = 79 ± 13 kg, age at launch = 43 ± 4 yr) were included in the study.

Equipment and Protocol

Ultrasound sessions on the ISS were completed in the morning, prior to donning the thigh cuffs (Pre-cuff), and after 4 h of thigh cuffs, with the cuff still in place (Cuff). During each session, consecutive ultrasound scans were performed with two probes, using a customized Orcheo Lite scanner (ECHO Sonoscanner, Paris, France). First, the 2D scans were collected using a 17-mHz linear probe. Participants were remotely guided by a sonographer on Earth to place the probe at the right clavicle (with the IJV in the center of the image) and slide up the neck toward the mandible while maintaining light contact pressure (Fig. 1, left). The length of time it took to image from the clavicle to the mandible varied. The 2D slide was repeated three times, and the image with the most consistent IJV wall was selected for analysis. Second, the 3D scans were collected using a custom motorized 3D linear probe (described above) which was placed by the participant at the right clavicle, in contact with the trachea, using light contact pressure (Fig. 1, right). The sonographer on the ground adjusted the image as necessary, then initiated the automated, robotically controlled 3D capture sequence. Three repetitions of the capture were completed, and the best image was analyzed. No statistics were completed on data due to the small sample size.

Analysis

The 2D ultrasound imaging was analyzed by extracting individual frames from the exported cine video file (∼120–350 frames per cine) (VLC Media Player; https://www.videolan.org/vlc/index.html). The IJV CSA in each frame was quantified semiautomatically using the ellipse tool in ImageJ (http://imagej.org/) and adjusted manually. Any frame when the probe was stationary or the IJV walls could not be identified was discarded. Frames were then normalized to the distance covered by the scan, where the first frame at the clavicle was made 0% and the final frame at the mandible was made 100%. All measurements were averaged to quantify mean IJV CSA across the vessel.

The 3D ultrasound analysis was completed using customized software on the Orcheo Lite scanner (**Fig. 2A**). The software automatically pulls nine images of IJV CSA, which are then measured by manually tracing the inner wall of the vessel in each of the nine images using the track pointer of the device (**Fig. 2B**). Mean CSA value and scan length (3.6 cm) were used to calculate IJV volume. In addition, all measurements were averaged to quantify mean IJV CSA across the vessel in order to facilitate comparison to the 2D data.

RESULTS

Compared to 2D ultrasound, IJV CSA was larger with 3D ultrasound during Pre-cuff (3D: 1.19 ± 0.34 cm^2; 2D: 0.84 ± 0.35 cm^2) and smaller with 3D ultrasound during Cuff (3D: 0.79 ± 0.28 cm^2; 2D: 0.83 ± 0.33 cm^2) (Fig. 1). The intraindividual absolute and relative change in IJV CSA between Precuff and Cuff measurements was inconsistent

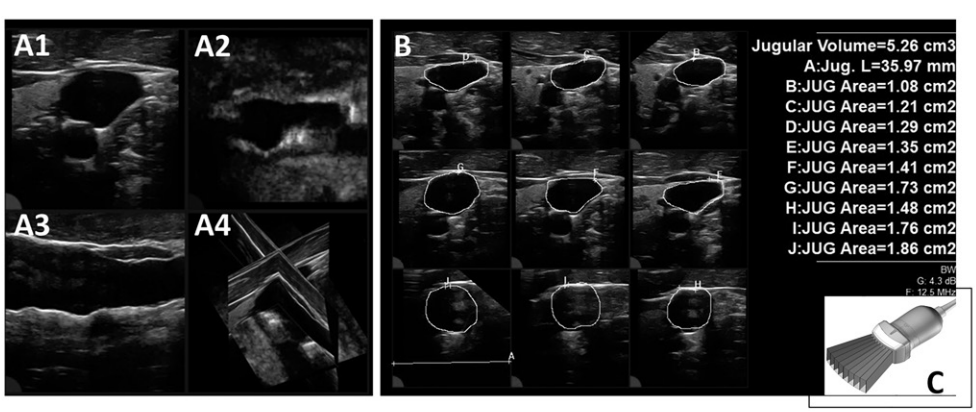

Fig. 2. Left panel shows the 3D scan acquisition planes (A1–A3: transverse, c-plane, and sagittal, respectively) and the user-movable transverse and sagittal axes (A4). In the A4 panel, the user slides the axial planes to optimize the internal jugular vein. Right panel (B) shows the 9 cross-sections of a representative IJV, and their corresponding areas taken equally spaced over 35.97 mm perpendicular to the long axis, moving from the collarbone toward the mandible. Inset (C) schematic shows the beamforming pattern used to create the nine cross-sections.

Table I. Internal Jugular Vein (IJV) Cross-Sectional Area (CSA) for All Crewmembers Using the 2D and 3D Ultrasound.

		IJV AREA (cm^2)		
CREWMEMBER	ULTRASOUND	PRE-CUFF	CUFF	% CHANGE
A	2D	0.63 ± 0.10	0.60 ± 0.10	−5%
	3D	0.81 ± 0.10	0.52 ± 0.09	−36%
B	2D	1.26 ± 0.27	0.85 ± 0.34	−32%
	3D	1.46 ± 0.27	1.06 ± 0.30	−28%
C	2D	0.76 ± 0.32	0.93 ± 0.34	+24%
	3D	1.31 ± 0.17	0.78 ± 0.07	−40%

2D CSA was the average of multiple measurements along the length of the IJV. The plane of the image could not be guaranteed to be 90° to the neck. 3D CSA was the average of nine sections taken equally spaced by the internal software of the Sonoscanner ultrasound. Each image was adjusted by the software to be perpendicular to the neck.

between 2D and 3D methods (**Table I**). Using 3D ultrasound, thigh cuffs were associated with ~35% reduction of IJV distention, with CSA being reduced in all 3 participants. With 2D ultrasound, CSA was reduced during Cuff in only two of three participants. In contrast, Crewmember C appeared to have a 40% increase, rather than decrease, in IJV distension with thigh cuffs (Fig. 1, Table I).

DISCUSSION

In this brief report, we confirmed that the use of thigh cuffs over 4 h reduced IJV CSA and volume in three astronauts. This report is limited to three astronauts because the 3D probe was not launched to ISS until part of the way through the Vascular Echo study. Additional astronauts were studied with thigh cuffs using only the 2D method. Interestingly, those data displayed similar ambiguity and inconsistent results to the 2D data presented here. Those 2D-only datasets have not been included because no 3D comparison data is available. The motorized 3D ultrasound technology mitigates human scanning errors created by nonexpert sonographers, even under remote guidance, by equalizing down pressure, controlling probe speed (which is important for reconstructing a realistic 3D view), and correcting the angle of insonation. Historically, IJV scans completed on the ISS have relied on 2D ultrasound, using conventional nonmotorized ultrasound, with remote voice-guiding from Earth.[3] The IJV is an irregular shape (see Fig. 1 and 2), so a long section with multiple CSA measurements should be analyzed to appropriately assess changes in volume. The current results demonstrate that when trying to capture a continuous image along the length of the IJV, using a motorized 3D ultrasound should be the preferred imaging method, and any 2D ultrasound results should be interpreted with extreme caution. It is not realistic to expect a nonsonographer crewmember to rigidly maintain the angle of insonation while sliding the probe 6 cm along their own neck. The motorized probe, even though it only covers 4 cm, has the clear technological advantage for correct angle of insonation. These data are the first to compare the outputs of both methods during spaceflight and with the same participants in the context of a known intervention/countermeasure that reduces IJV congestion.

In conclusion, although Hamilton et al.[3] provided visual evidence of the impact of thigh cuffs on IJV CSA, this is the first study to quantify the effects of cuffs at multiple levels of the IJV during spaceflight. Using only the 3D data, we found that 4 h of wearing thigh cuffs reduced venous congestion by ~35%. While conventional 2D ultrasound in the hands of an expert sonographer can quantify IJV CSA at the bedside, astronauts are generally not skilled sonographers, and motorized 3D ultrasound provides quantitative analysis that is preferable to assess microgravity-induced changes in volume of the irregularly shaped IJV.

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