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● *Technical Note*

ULTRASOUND MONITORING OF JUGULAR VENOUS PULSE DURING SPACE MISSIONS: PROOF OF CONCEPT

Paolo Zamboni,* Francesco Sisini,*,† Erica Menegatti,* Angelo Taibi,† Giacomo Gadda,† Valentina Tavoni,† Anna Maria Malagoni,* Mirko Tessari,* Sergio Gianesini,* and Mauro Gambaccini†

* Vascular Diseases Center, University of Ferrara, Cona, Ferrara, Italy; and † Department of Physics and Earth Sciences, University of Ferrara, Ferrara, Italy

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Abstract—The jugular venous pulse (JVP) is one of the main parameters of cardiac function and is used by cardiologists in diagnosing heart failure. Its waveform comprises three positive waves (a, c and v) and two negative waves (x and y). Recently, it was found that JVP can be extrapolated from an ultrasound (US) video recording of the internal jugular vein (IJV), suggesting its application in space missions, on which US scanners are already widely used. To date, the feasibility of assessing JVP in microgravity (microG) has not been investigated. To verify the feasibility of JVP assessment in microG, we tested a protocol of self-performed B-mode ultrasound on the International Space Station (ISS). The protocol consisted of a video recording of IJV synchronized with electrocardiogram that produces a cross-sectional area time trace (JVP trace) (in cm^2). The scans were acquired in six experimental sessions; two pre-flight (BDC1 and -2), two in space (ISS1 and -2) and two post-flight (Houston PF1, Cologne PF2). We measured the mean and standard deviation of the JVP waves and the phase relationship between such waves and P and T waves on the electrocardiogram. We verified that such parameters had the same accuracy on Earth as they did under microG, and we compared their values. The sensitivity, specificity and accuracy of JVP trace in microgravity are higher than those on Earth. The sequence of (a, c, and v) ascents and (x and y) descents along the cardiac cycle in microG is the same as that on Earth. The cause-and-effect relationship between the P and T waves on the electrocardiogram and a and v waves, respectively, of JVP is also confirmed in microG. Our experiment indicated the feasibility of deriving a JVP trace from a B-mode US examination self-performed by an astronaut in microG. (E-mail: ssf@unife.it)

Key Words: **Internal jugular vein, Jugular venous pulse, Microgravity.**

INTRODUCTION

Since the 1970s, cardiovascular research under microgravity (microG) conditions has been performed in several experiments on astronauts during space missions (Buderer et al. 1976). One of the first diagnostic modalities for studying the cardiovascular system available in space missions was the ultrasound (US) scanner. It has been used for many different applications, including echocardiography and US Doppler of the major head and neck vessels. However, US has never been used to assess the jugular venous pulse (JVP) in astronauts.

Address correspondence to: Francesco Sisini, Department of Physics and Earth Sciences, University of Ferrara, Via Saragat 1, 44122 Ferrara, Italy. E-mail: ssf@unife.it

The JVP is one of the main parameters of cardiac function, and cardiologists consider it as a prognostic factor in chronic heart failure (Applefeld 1990; Mackay 1947; Mackenzie 1902). It comprises three positive waves (a, c and v) and two negative waves (x and y). Recently, it was reported that the JVP can also be extrapolated from the time diagram of the internal jugular vein (IJV) cross-sectional area (CSA) obtained by analyzing a US video file (Nakamura et al. 2016; Sahani et al. 2016; Sisini et al. 2015a, 2015b; Zamboni 2016) from a conventional US scanner.

To date, an experiment determining the feasibility of assessing the JVP using a US scanner in microG has not been performed. B-Mode US data are available for the CSA of the IJV under microG conditions (Hamilton et al. 2011), but these data consist of single measurements of IJV CSA frozen in an undetermined moment of the cardiac cycle and are not suitable for tracing a CSA time diagram along the cardiac cycle.

Therefore, we designed the DrainBrain protocol for the acquisition of B-mode US data; this protocol included self-performed US scanning of the IJV by an astronaut. The project was sponsored by the Italian Space Agency. US was performed by an astronaut of the European Space Agency (ESA) during a long-duration mission to the International Space Station (ISS) (National Aeronautics and Space Agency [NASA] 2015). The aim of this study was to provide proof of concept for the feasibility of measuring JVP variations before, during and after the experiment in microG.

METHODS

All experiments were performed in accordance with the relevant guidelines and regulations. The study was approved by the institutional review boards of the University Hospital of Ferrara (Italy), NASA and ESA. Informed consent was provided by the astronauts before the study.

JVP extraction and analysis of the trace

Acquisition protocol. A 37-y-old female astronaut underwent a series of cross-sectional scans of bilateral IJVs using the Vivid-Q scanner (GE Medical Systems Ultrasound, Horten, Norway). The scans lasted approximately 30 s on each side and were saved as a video file. The ultrasound device was integrated within the Human Research Facility, which was already available on the ISS. The instrument was set to 30 frames/s resolution before each experiment. Good hydration was recommended on the day of the experiment. Therefore, the astronaut was advised to drink 500 mL of water approximately 1 h before the experiment. The scans were acquired in six experimental sessions (see Table 1); the first and second (BDC1 and BDC2) were performed at the European Astronaut Centre of the ESA at Cologne, Germany. The experiment was performed at approximately 8:00 AM immediately after the astronaut woke up. The astronaut was in the supine position and performed the scan on herself after relevant training. The scanning began within 1 min of the astronaut's lying down. Both IJVs were scanned; the right IJV was scanned followed by the left.

The third and fourth (ISS1 and ISS2) sessions were performed on board the ISS by the astronaut on herself. ISS1 was performed a few days after the start of the mission, and ISS2, just before her return after 6 mo in space. The fifth and the sixth sessions (Houston PF1 and Cologne PF2) were performed as per the protocol in Houston at the Johnson Space Centre of NASA and at Cologne by one of the authors. The video files obtained in Cologne and Houston were exported from the US machine using routine export methods, whereas the video files obtained in space were sent *via* satellite transmission. All videos were analyzed on Earth.

Table 1. Experimental sessions on the ISS that were analyzed

Session	Date	Days since BDC
BDC1	27/08/2014	0
BDC2	30/09/2014	34
ISS1	28/11/2014	93
ISS2	28/04/2015	244
Houston PF1	17/06/2015	294
Cologne PF2	16/07/2015	323

BDC1 (2) = first (second) session performed at the European Astronaut Centre of the European Space Agency at Cologne, ISS1 (2) = third (fourth) session performed on board the International Space Station, Houston PF1 = fifth session performed post-flight at Houston, Texas, USA, Cologne PF2 = sixth session performed post-flight at Cologne, Germany.

Offline production of the JVP trace from US video clip. For each of the 12 videos, IJV CSA was measured in each video sonogram; a CSA time trace was thus obtained from each video. The detailed procedure used to obtain the sequence of CSA measurements is described elsewhere (Sisini et al. 2015a, 2015b). The quality of the JVP traces was tested with respect to sensitivity (SE), specificity (SP) and accuracy (AC) (Sisini et al. 2015a, 2015b). We measured a set of parameters a, v, x and y for each JVP trace. The amplitudes of IJV CSA corresponding to the positive waves a and v and negative waves x and y, during the ith cardiac cycle, are here indicated by parameters a_i, v_i, x_i and y_i (see Fig. 1). We did not consider the c wave because the time resolution used for the US video (30 frames/s) did not allow for its accurate detection. All JVP parameters are herein quantified in square centimeters. These parameters were recorded on the trace using a semi-automatic procedure described in Sisini (2016) and then cross-checked by one of the authors. Furthermore, we measured the parameters Δa and Δv for every cardiac cycle recorded (see Fig. 1). Δa is defined as the difference in the amplitudes of waves a and x in the JVP traces, and Δv is defined as the difference in the amplitudes of waves v and y in the JVP traces. The intervals between waves a and x (Δt_{ax}) and waves v and y (Δt_{vy}) were also measured.

The means and standard deviations of the parameters a_i, v_i, x_i, y_i, Δa_i, Δv_i, Δt_{ax_i} and Δt_{vy_i} were calculated from approximately 30 cardiac cycles. Because it has been reported that US JVP time traces contain signals from the heart, respiration and probably Mayer waves (Julien 2006), the discrete Fourier transform (DFT) algorithm was used to identify the periods of such signals in the JVP time trace (Smith et al. 2016). DFTs of the CSA traces were