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# Microgravity Changes detected by Carotid Hemodynamic Monitoring in Astronauts

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## *Abstract*

*This study assessed the viability of continuous hemodynamic monitoring for space missions, emphasizing the importance of venous hemodynamic monitoring due to microgravity's impact. Machine learning analyzed pulse wave data from four astronauts' carotid arteries and jugular veins before and after a 17-day mission, effectively classifying three hemodynamic waveform variants that change in prevalence following microgravity exposure compared to preflight baseline. Jugular vein changes were significantly more pronounced than arterial changes (p=0.02 vs. p=0.06). Significant differences in the diastole waveform shape between the baseline prevalent waveform variant and that of the prevalent waveform following exposure were observed (p<0.00001). Further studies are required to evaluate the role of venous monitoring in astronaut health during space missions.*

**Keywords:** Pulse Wave Velocity, Deep learning, Carotid Artery, Hemodynamics, microgravity, space mission, Spaceflight Associated Neuro-Ocular Syndrome (SANS)

## Introduction

As the feasibility of human expeditions to Mars advances, the problem of redistribution of blood flow toward the upper body becomes more concerning.[1] Microgravity changes the distribution of bodily fluids, resulting in a net migration from the legs toward the upper body. This cephalad fluid shift may increase intracranial pressure, contributing to conditions such as Spaceflight-Associated Neuro-Ocular Syndrome (SANS), characterized by clinical symptoms such as optic disc edema.[2,3] Thus, injury assessment and addressing SANS challenges is essential for the safety and success of extended space missions.[4]

Artificial Intelligence (AI) tools represent a transformative force in medicine, enhancing diagnostics through their capacity to process and analyze vast amounts of data with unparalleled efficiency. Deep learning, a subset of AI, is highly effective in recognizing complex data patterns that are often imperceptible to the human eye, enabling novel insights from large medical datasets. These advanced AI methodologies are advantageous when analyzing intricate variations across multiple datasets, especially in scenarios with subtle changes, such as fluid shifts over time. Moreover, we can integrate AI in continuous, noninvasive monitoring systems today, leading to real-time analysis and decision-making support, significantly enhancing patient care efficacy.

This study explores the use of deep learning to detect microgravity-induced changes in the continuous monitoring of the carotid artery and jugular vein.

## Methods

**Data acquisition:** Four astronauts (mean age 64±7 years) participated in this study, which was approved by the Sheba Helsinki Committee and Axiom Space. All participants signed an informed consent. Data was acquired with the StrokeSense101, a system developed based on three piezoelectric bimorph sensors (SMBS1515T6P750WL; StemInc) set 1.5 cm apart, and a data acquisition device (1608FS; Measurement Computing) sampling at 1 kHz. An Electrocardiogram (ECG) monitoring was incorporated into data acquisition. Four sensor triplets were attached to each astronaut's neck by a trained physician (IM). Two sensors, one per side, were attached over each carotid artery under the jaw and over each external Jugular vein. The carotid sensor was positioned based on pulse palpation. The jugular venous pressure was observed via visualization of the internal jugular vein pulsations of the neck when supine. Astronauts were monitored in three sessions. The first, 'preflight,' measurement was taken before departure to the International Space Station (ISS). The second, "postflight" (after17 days in space), was shortly upon return to earth (~5 hours, R+0). The third and final measurement was taken the day after landing and is referred to as "Next Day" (16-22 hours after splashdown following a full sleep period; R+1). On each occasion, two measurements were taken: one while the participant was seated (2 minutes) and another while lying supine (3 minutes). Participants were instructed to remain silent and still during data recording.

**Data analysis.** All analysis was performed using homemade Python scripts (version 3.10.13). We used a butterworth bandpass filter between 0.5-25 Hz to isolate relevant frequency components and Z-scoring normalization to standardize the data. Pulse waves were isolated by segmenting the data based on ECG-based windowing.[5] The quality of the pulse waveform was determined based nominal waveforms found in the literature. We graded the quality of each wave and used only the top 10th percentile of data with the best quality for analysis.[6,7] Due to similar statistics, data was pooled across sensor side and participant position. ***AI Algorithm:*** Pulse waves were passed through a convolutional neural network (CNN) that performed a dimensionality reduction. The resulting reduced representation of the pulse waves was passed through a k-means algorithm to cluster pulse waves into 3 clusters (Figure 1). Following the AI algorithm's data processing, we analyzed the proportion of each type in each session. This process was repeated independently for each astronaut and each sensor position (arterial and vein).

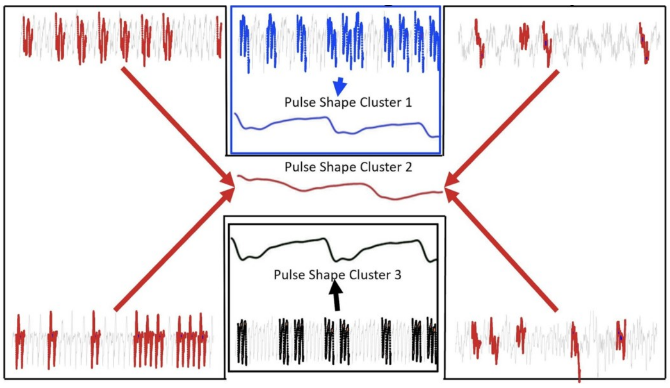

**Figure 1: Illustrative Example of Pulse Wave Clustering:**

For each astronaut, pulse waves from all sessions that passed through the quality filter underwent a dimensionality reduction using a convolutional neural network and then clustered into 3 clusters (red, blue, and black). The prevalence of each cluster in a given session was calculated as the percent total of all pulse waves in that session.

**The area under the curve** To compare between clusters, we calculated the area under the curve of the normalized pulse wave from the dicrotic notch until the end of the pulse. The values were then normalized by dividing by the area under the curve of the complete pulse wave.

**Statistical analysis.** All measures of the effects of microgravity were assessed using an ANOVA or paired t-test in the case of paired comparisons. A p-value of 0.05 or less was considered statistically significant for all analyses.

## Results

### Change in Pulse Wave Type prevalence following exposure to microgravity.

There were three recording sessions: one preflight and two postflight. One immediately on return and the second (R+1) one day after splashdown. Pulse waves were categorized into three variants for each astronaut’s artery and vein (Figure 2a and 2b respectively) and categorized in a manner such that the first variant was the dominant one pre flight and the third variant was the dominant one shortly after splashdown (R+1). The predominant preflight waveform accounted for more than 50% (58±20% and 55±8% for artery and vein, respectively) during baseline, dropping to under 50% after microgravity exposure (R+0: 46±13.3% and 31±10% for artery and vein, respectively) with a partial recovery within 24 hours later (R+1: 50±11% and 37±17% for the artery and vein respectively; Figure 32c,d).

In contrast, the dominant variant post flight shows a reversed effect, accounting for only 21±13% and 10±8% for the artery and vein respectively pre flight, increased to account for 31±7% and 39±7% for the artery and vein respectively after landing, followed by a partial recovery the next day to account for 31±9% and 28±20% for the artery and vein respectively (Figure 2c,d).

A 2x3 repeated measures ANOVA of time (pre vs post flight) by variant type revealed a significant result of F(2,4)=20.5, p=0.002 in the jugular veins versus a result of F(2,4)=4.7, p=0.06 in the artery.

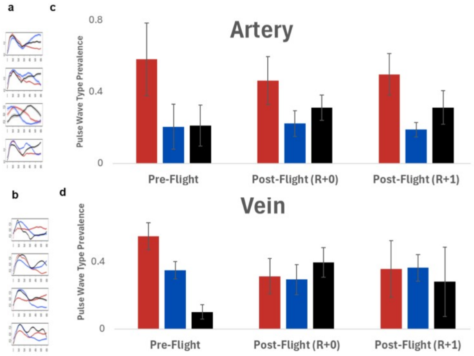

**Figure 2: Changes in Pulse Wave Type Preva-**

### lence Following Microgravity Exposure:

Pulse waves were clustered into three variants for each astronaut independently based on recordings over the artery (a) and the vein (b). While the clustering was independent for each astronaut, the variants were ordered so that the red variant was the dominant variant pre flight and the black variant was the dominant variant post flight (R+0). The red variant decreased in prevalence after landing with a partial recovery the next day (R+1), whereas the black variant increased in prevalence post flight (R+0) with a partial recovery the next day (R+1) in both the artery (c) and vein (d) recordings F(2,4) =4.7, $p=0.06$ and (F(2,4)=20.5, $p=0.002$ respectively.

### Change in pulse wave shape following exposure to microgravity.

While the clustering was done independently for each astronaut, each presented with distinct dominant variants pre and post flight To explore whether this indicated a shared change in pulse wave shape across all astronauts, we explored the area under the curve of the pulse wave variants following the dicrotic notch pooled across astronauts. The before-takeoff dominant variant had a normalized area under the curve of 0.22±0.1 and 0.22±0.13 for the artery and vein recordings, respectively, while the post flight dominant variant had a normalized area under the curve of 0.31±0.11 and 0.28±0.14 for the artery and vein recordings respectively (Figure 3). An independent t-test showed the differences between variants to be significant (T-value= -15, $p<0.00001$ and T-value= -7, $p<0.00001$ for the artery and vein recordings, respectively).

Along with a change in shape, there was also a change in the timing of the dicrotic notch. The pre-flight dominant variant's dicrotic notch was similar (250±40 and 260±40 miliseconds for the artery and vein recordings respectively). Post- flight dominant variant's dicrotic notch was prolonged for in the artery recordings (260±40 milliseconds ; T-value=-2.1, $p=0.003$) and shortened for the vein recordings (240±40 milliseconds; T-value=5.7, $p<0.00001$).

To further explore the effects of microgravity on the shape of the pulse wave following the dicrotic notch, we engineered features to input into a machine learning classifier of exposure to microgravity. The classifier had a value of 0.14±0.16 and 0.10±0.13 for the pre flight dominant variant for the artery and vein respectively that decreased to 0.10±0.13 and 0.07±0.12 for the post flight dominant variant for the artery (T-value=18, $p<0.0001$) and vein (T-value =13, $p<0.0001$) respectively.

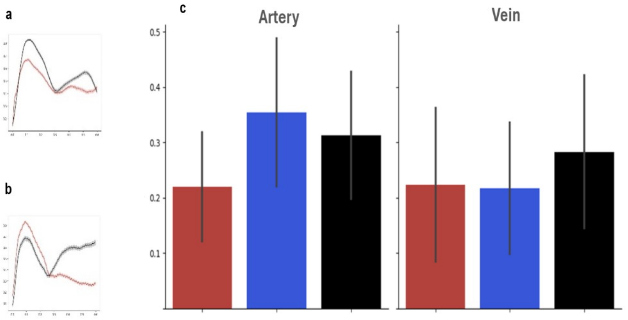

**Figure 3: Change in Pulse Wave shape following exposure to microgravity:**

In both artery (a) and vein (b) recordings, the post flight dominant variant (black) has a larger area under the curve (c) following the dicrotic notch than the pre- flight dominant variant (red).

### Discussion

In this study, we measured pulse waveforms to explore the hemodynamic effects of microgravity on astronauts. Our findings reveal that a short duration exposure to microgravity may exert a greater impact on venous return than on arterial resistance, aligning with clinical observations of venous thrombosis in space missions.[81] Notably, venous stasis and thrombosis have been reported on longer -duration spaceflights (e.g., 210 days).[2] However, our study detected measureable changes after just 17 days. We hypothesize that the propensity for fluid accumulation and stasis in veins may be attributed to their thin-walled musculature. Despite this, hemodynamic alterations were observed in both arterial and venous systems, with the latter exhibiting more pronounced changes similar to the clinical pathology reported in the litriture.[3]

Microgravity-induced changes were more evident in the vein than in the artery, which is more easily palpable. The practical implication of this findings is that precise sensor placement may be less critical than previously thought, potentially obviating the need for healthcare personnel and facilitating monitoring during space travel. Furthermore, our results were obtained through non-continuous monitoring, siting and standing with 2-3 minutes of recording sufficient to detect changes. This makes these measurements more feasible for implementation in space missions.

We observed an increased area under the curve for both arteries and veins, that may be indicative of congestion and fluid accumulation. The prolonged dicrotic notch in the carotid arteries may be due to the faster flow and lower resistance within the arterial tree.[9] The delayed dicrotic notch in the jugular veins warrants further investigation to elucidate its underlying mechanisms but may be influenced by stagnation and even reversal of flow documented.[10]

A key finding of our study is that waveform changes were not readily apparent upon visual inspection of the recorded signals. Our AI algorithm successfully identified a distinct 'fingerprint' of waveform changes indicative of early stroke, differentiating between baseline and microgravity exposure. This highlights the potential of AI in enhancing the sensitivity of hemodynamic monitoring. Nevertheless, the 'black box' nature of deep learning models poses a challenge in interpreting their decision-making processes. To address this, we complemented the AI analysis with traditional pulse wave evaluations.

Despite the small sample size (n=4), our study identified significant hemodynamic changes using AI-assisted pulse wave analysis. Although more research is needed, this study shows promise for AI -assisted pulse wave analysis to serve as a valuable tool for monitoring and assessing hemodynamic and cardiovascular risk during spaceflight. This is particularly important given the need for novel diagnostic tools as humans look towards deep space exploration and missions of increasing duration. It also illustrates the importance of applying and adapting novel terrestrial diagnostic tools, such as pulse wave analysis and AI-assisted technology, to the spaceflight environment.

In conclusion, our study demonstrates that hemodynamic changes can be detected through AI-assisted pulse wave analysis, which could serve as a valuable tool in future spaceflight missions. This approach has the potential for enhancing the detection and intervention of vascular conditions in space missions. Further research is required to validate these findings in real-time space missions and assess their broader implications.

## Geolocation information

This study originated in Israel and took place at

Florida, USA.

## Acknowledgment

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## Statement of Ethics

The study was approved by the Sheeba Helsinki committee and Axiom mission .

## Disclosure statement

Itamar Machol, Michelle Hong Chan. and Harel Baris have no conflict of interest to disclose. Samuel Zibman, Samuel Goldstein, Shirley Ackerman, Meron Ben Pazi, and Ori Shriki are Avertto employees. Shady Jahshan, Marc Ribo, and Sagi Har-Nof are Avertto's principal investigators. Hilla Ben Pazi, MD, is the founder and CEO of Avertto.

## Author Contributions

Author contributions are as follows: data acquisition (IM, MHC, HB), data analysis (SZ, SG), or data interpretation (OS, MBP, YK). The paper was drafted (HBP) and critically reviewed for important intellectual content (MR, SZ, SG) with the final approval of the version to be published (SJ, SHN). All authors are accountable for all aspects of the study.

## Data Availability Statement

Data will be available upon request for academic use.

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