

Post-Landing Orthostatic Intolerance after Spaceflight: Characterization of Intravenous Fluid Resuscitation in NASA Astronauts

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Abstract

Post-landing orthostatic intolerance (OI) is a prevalent consequence of spaceflight and is often empirically treated with intravenous fluids (IVF) post-landing. Yet IVF administration lacks evidence-based guidelines. We conducted a retrospective review of de-identified flight surgeon documentation for 79 astronauts returning from International Space Station missions (2001–2023). Nausea was documented in 39.2% astronauts, vomiting in 27.8%, dizziness or vertigo in 25.3%, and neurovestibular symptoms in 79.7%. IVF were administered to 41.8% astronauts, with marked variability in bolus volume (500–4000 mL). Female sex was associated with higher rates of nausea ($p = 0.014$) and lightheadedness ($p = 0.033$); older age with vomiting ($p = 0.037$). No individual symptom significantly predicted IVF administration. Hemodynamic triggers and post-infusion reassessment were inconsistently documented. Post-landing management varied substantially, with heterogeneous IVF practices and limited protocolized documentation, underscoring the need for standardized, physiology-informed operational guidelines, particularly for future deep-space missions with constrained medical resources.

INTRODUCTION

Post-landing orthostatic intolerance (OI) is a ubiquitous and frequently encountered clinical problem in spaceflight participants upon return from the microgravity of space back to Earth.^{1–3} Up to 30% astronauts returning from short-term duration missions and nearly 80% returning from long-duration spaceflights experience symptoms consistent with OI.⁴ These may include lightheadedness, presyncope, palpitations, or overt orthostatic hypotension. The symptoms clinically correspond to frank orthostatic hypotension, reflex syncope mediated by the vestibular system, or postural orthostatic tachycardia syndrome (POTS).⁴ The underlying pathophysiology is attributed to baroreceptors unloading, impaired autonomic response, and the vestibular dysfunction that develop in microgravity and become unmasked upon rapid transition to Earth's gravitational field⁵. These mechanisms are further exacerbated by microgravity-associated plasma volume loss and relative intravascular depletion.⁶

A variety of countermeasures and treatments have been explored to mitigate and treat post-landing OI. Non-specific countermeasures, such as preserving cardiovascular fitness and muscle mass appear to be effective and have been widely used.^{5,6} Other non-pharmacological measures, including anti-G suits, artificial gravity, or lower body negative pressure training may provide benefit but are not universally protective.⁷ Pharmacological approaches such as volume loading prior to landing, midodrine, and fludrocortisone have also been evaluated, yet none reliably prevents symptomatic OI. Consequently, many astronauts continue to develop clinically significant symptoms that require acute management following landing.

In current NASA practice, symptomatic OI is typically managed with intravenous fluids (IVF) and antiemetics at the discretion of flight surgeon. However, indications, dosing strategies, and documentation practices are not standardized. In terrestrial emergency and perioperative care, fluid

administration is generally guided by defined physiologic targets and reassessment. Whether similar principles are consistently applied in the post-spaceflight setting is not well characterized.⁸

The present study aimed to characterize the current clinical management of post-landing OI in NASA astronauts. Using retrospective data extended from flight surgeon documentation, post-landing symptom patterns, vital sign abnormalities, medication use, and IVF administration practices were described, and associations with demographic characteristics were explored. By delineating current operational practice, this analysis establishes a foundation for the development of structured, physiology-informed treatment protocols for post-landing OI in both routine recovery and future exploration missions.

METHODS

Study design and data source

A retrospective observational study was conducted using de-identified medical documentation generated during routine post-landing recovery operation for NASA astronauts. This study was reviewed by NASA Institutional Review Board (IRB 20-009205) in Washington, D.C. and was designated as non-human subject research. All data were de-identified prior to being released to the investigators. The dataset was compiled by the NASA Lifetime Surveillance of Astronaut Health (LSAH) as part of a broader data extraction that also supported a parallel study examining neurovestibular symptoms after landing. This study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.⁷

Study population

American astronauts returning from International Space Station missions between years **2001 and 2023** were included. The observation period extended from landing (day 0) through day 3 after landing. Each astronaut contributed a single analytic record. When multiple entries were available, clinical features were coded as present if documented at any time during the observation window.

Baseline variables

Baseline characteristics included sex and age category (< 46 and 46–60 years). Mission duration was categorized (< 170 and 170–350 days) for male astronauts; duration for female astronauts was unavailable because of de-identification constraints. Clinical variables were abstracted and grouped into five domains: i) symptoms consistent with orthostatic intolerance (nausea, vomiting, dizziness or vertigo, and orthostasis); ii) neurovestibular findings; iii) vital signs abnormalities (hypotension, hypertension and bradycardia); iv) intravenous fluid administration; v) antiemetic use.

All variables were abstracted from documentation and coded as present or absent. Intravenous fluid administration was characterized by timing (day 0 vs subsequent days), initial bolus volume, and total volume administered.

Data handling

Missing data were not imputed. Analyses were conducted using available observations.

Statistical analysis

Because of mixed data types and variable completeness across participants, analyses were primarily descriptive. Categorical variables are reported as counts and percentages, and continuous variables as medians with ranges. Associations between age category and clinical features were evaluated using chi-square tests of independence. Among male astronauts, associations between mission-duration category and clinical features were similarly evaluated using chi-square tests; Fisher's exact test was used when expected cell counts were fewer than five. Associations between sex and clinical features were assessed using chi-square or Fisher's exact tests, as appropriate.

To evaluate clinical features associated with receipt of intravenous fluids, multivariable logistic regression models were constructed including dizziness or vertigo, nausea, vomiting, orthostasis, and neurovestibular findings as covariates. Associations between clinical features and receipt of intravenous fluids were evaluated using univariable logistic regression models. Results are reported as odds ratios with 95% confidence intervals.

All analyses were performed using JASP (version 0.95.4).⁹ A two-sided P value of less than 0.05 was considered statistically significant. No adjustment for multiple comparisons was performed.

RESULTS

Baseline characteristics

A total of 79 astronauts were included in the analysis, including 19 women and 60 men. Age category and mission duration distributions are shown in Table 1. Thirty participants (38.0%) were younger than 46 years, and 49 (62.0%) were 46–60 years of age. Among male astronauts, mission duration was less than 170 days in 29 (48.3%) and 170–350 days in 31 (51.7%).

Table 1
Age distribution of the study cohort

Characteristics	Female (n = 19)	Male (n = 60)	Overall (n = 79)
Age < 46 year.	13 (68.4%)	17 (28.3%)	30 (38.0%)
Age 46–60 year.	6 (31.6%)	43 (71.7%)	49 (62.0%)
Mission duration < 170 days	N/A	29 (48.3%)	N/A
Mission duration 170-350 days	N/A	31 (51.7%)	N/a
Mission duration data were not available for female participants due to de-identification constraints.			

Post landing symptoms and clinical findings

Symptoms consistent with orthostatic intolerance were common (Table 2). Overall, nausea was documented in 31 astronauts (39.2%), vomiting in 22 (27.8%), dizziness or vertigo in 20 (25.3%), and orthostasis in 9 (11.4%). Neurovestibular findings were recorded in 63 astronauts (79.7%).

Table 2
Documented post-landing symptoms and clinical findings and hemodynamic abnormalities during early post-landing recovery

Clinical variable	Female (n = 19)	Male (n = 60)	Overall (n = 79)
Nausea	12 (63.2%)	19 (31.7%)	31 (39.2%)
Vomiting	5 (26.3%)	17 (28.3%)	22 (27.8%)
Dizziness or vertigo	5 (26.3%)	15 (25.0%)	20 (25.3%)
Orthostasis	2 (10.5%)	7 (11.7%)	9 (11.4%)
Neurovestibular findings	18 (94.7%)	45 (75.0%)	63 (79.7%)
Blood pressure abnormalities			
Hypotension	2 (10.5%)	1 (1.7%)	3 (3.8%)
Hypertension	4 (21.1%)	10 (16.7%)	24 (17.7%)
Heart rate abnormalities			
Tachycardia	3 (15.8%)	2 (3.3%)	5 (6.3%)
Bradycardia	0	5 (8.3%)	5 (6.3%)
Hemodynamic abnormalities were coded as present when explicitly documented in flight surgeon records at any time during the observation period.			

Among women, 15 of 19 (78.9%) experienced symptoms consistent with orthostatic intolerance on the day after landing. Nausea was most frequent (63.2%), followed by lightheadedness (26.3%), dizziness or vertigo (26.3%), and vomiting (26.3%). Neurovestibular findings were present in 94.7% of female astronauts on day 0 and persisted through day 3 in 42.1%. Among men, 32 of 60 (53.3%) experienced symptoms. Nausea occurred in 31.7%, vomiting in 28.3%, and dizziness or vertigo in 25.0%. Neurovestibular findings were documented in 75.0% on day 0 and in 38.3% on day 3.

Hemodynamic abnormalities were infrequently documented. Hypotension occurred in 3 astronauts (3.8%), hypertension in 14 (17.7%), tachycardia in 5 (6.3%), and bradycardia in 5 (6.3%). These abnormalities were episodic and most often limited to the day of landing.

Associations with demographic characteristics

Among male astronauts, mission duration was not significantly associated with nausea, dizziness or vertigo, vomiting, orthostasis, or neurovestibular findings (all $P > 0.05$; **Supplemental Table 1**). When stratified by sex, nausea ($P = 0.014$) and lightheadedness ($P = 0.033$) were more frequently documented among female participants, whereas dizziness or vertigo, orthostasis, neurovestibular findings, and vomiting did not differ significantly between sexes (**Supplemental Table 2**). In age-stratified analyses, vomiting was more common among participants 46–60 years of age than among those younger than 46 years (36.7% vs. 13.3%; $\chi^2=5.07$, $P = 0.037$; Cramér's $V = 0.253$), whereas other symptoms did not differ significantly by age category (**Supplemental Table 3**).

Administration of intravenous fluids

Intravenous fluids were administered to 33 of 79 astronauts (41.8%), as shown in Table 3. Ten of 19 women (52.6%) and 23 of 60 men (38.3%) received at least one bolus ($P = 0.42$). Initial bolus volumes ranged from 500 to 4000 mL. Median initial bolus volume was 1350 mL (range, 1000–2000) in women and 1000 mL (range, 500–1000) in men. Most boluses were administered on day 0 at the landing site or during transport. Repeat boluses were given to 7 women (≥ 2 boluses in 5.3%) and 6 men (10.0%), and ≥ 3 boluses were uncommon. Total administered fluid volumes varied widely, with a median total of 1850 mL (range, 1000–2500) in women and 1000 mL (range, 500–3000) in men (Fig. 1). Notably, contemporaneous hemodynamic triggers for fluid administration were inconsistently documented, and serial reassessment after infusion was rarely recorded.

Table 3
Intravenous fluid (IVF) administration during early post-landing recovery

Group	IVF received n (%)	First bolus median (range), mL	≥ 2 boluses n (%)	≥ 3 boluses n (%)	Total IVF volume median (range), mL
Female (n = 19)	10 (52.6%)	1350 (1000–2000)	1 (5.3%)	1 (5.3%)	1850 (1000–2500)
Male (n = 60)	23 (38.3%)	1000 (500–1000)	6 (10.0%)	1 (1.7%)	1000 (500–3000)

Clinical Features Associated with Receipt of Intravenous Fluids

In univariable logistic regression analyses (**Supplemental Table 4**), no individual symptom was significantly associated with receipt of intravenous fluids. Vomiting demonstrated the largest magnitude of association (odds ratio, 5.83; 95% CI, 0.64–52.88; $P = 0.117$), although the confidence interval was wide. Nausea (odds ratio, 1.05; 95% CI, 0.21–5.19), dizziness or vertigo (0.89; 95% CI, 0.34–11.18), lightheadedness (0.81; 95% CI, 0.13–4.91), and orthostasis (0.97; 95% CI, 0.09–10.04) were not associated with intravenous fluid administration. An odds ratio for neurovestibular findings was not estimable because of quasi-complete separation. Neither age category nor mission duration were significantly associated with receipt of intravenous fluids or total fluid volume administered.

Administration of antiemetics

Promethazine was administered to 8 astronauts (10.1%). Use was infrequent and not significantly associated with sex, age category, mission duration, symptom presence, hemodynamic abnormalities, or receipt of intravenous fluids (all $P > 0.05$).

DISCUSSION

In this retrospective review of NASA flight surgeon documentation, we observed that a substantial proportion of astronauts developed symptomatic OI after landing, with nausea, vomiting, dizziness, and neurovestibular findings representing the predominant clinical features. These results align with prior research demonstrating persistent cardiovascular and sensorimotor instability during early recovery, and they underscore the need for reliable, operationally feasible countermeasures.^{10–13} While those symptoms were present across both sexes and all age groups, we found that female sex constituted a risk factor for nausea and lightheadedness whereas older age for vomiting. This finding somewhat corroborates terrestrial literature whereby female sex but not older age is associated with both motion sickness and post-anesthesia nausea and vomiting^{14,15}.

A central observation of this study is the marked variability in the administration of intravenous fluids (IVF) during post-landing recovery. Fluid bolus volumes ranged widely, from 500 mL to 4000 mL, and were administered across multiple operational settings, often without documented hemodynamic triggers such as hypotension or tachycardia. In several cases, IVF was administered despite normal or elevated blood pressure; conversely, some astronauts with documented hemodynamic instability did not receive fluid resuscitation. This variability highlights the absence of a standard protocol and reveals the extent to which treatment decisions rely on individual clinical judgment, the operational environment, and the subjective interpretation of symptoms.

This contrasts to terrestrial medical practice, where fluid resuscitation follows structured algorithms informed by validated physiologic thresholds and serial reassessment^{16,17}. In emergency, critical care, and perioperative environments, indications for crystalloid administration are tied to quantifiable parameters, mean arterial pressure, shock indices, orthostatic vital sign criteria, or dynamic assessments of volume responsiveness.^{18,19} These data-driven frameworks are absent from current spaceflight medical operations. Instead, fluid administration occurs in an environment with limited monitoring, substantial time pressure, variable access to equipment, and competing operational demands. The result is an understandable but clinically significant heterogeneity in care.

For future exploration missions, such variability carries important operational implications. In contrast to the current low Earth orbit (LEO) operations, where post-landing medical support is immediately available and orthostatic symptoms are managed in a controlled recovery environment with no additional high-demand tasks expected, astronauts undergoing missions to the lunar surface or Mars be required to ambulate, perform -critical tasks, and operate with limited medical infrastructure shortly after landing while facing prolonged microgravity exposure, delayed communication, and limited immediate medical support.²⁰ IVF supplies will be constrained by mass, volume, and storage considerations. Astronauts may need to self-administer treatments using simplified protocols. Without evidence-based criteria to guide when and how fluids should be given, both under-treatment and over-treatment become possible, with downstream effects on crew capability and mission safety. Establishing structured, physiology-informed guidelines -potentially incorporating wearable sensors, pre-landing risk stratification, and decision aids- will be essential to reducing uncertainty in post-landing care.

This study has several limitations inherent to the operational dataset. Documentation was narrative and inconsistent across missions, leading to missing or intermittently recorded data. Vital signs and symptoms were not collected at standardized intervals, and IVF administration was often not accompanied by follow-up assessments to evaluate treatment effect. Flight duration data were unavailable for female astronauts due to de-identification constraints, limiting the ability to explore duration-related risk, and the baseline characteristics, such as age, differed between males and females. Finally, the retrospective design precludes causal inference. Despite these limitations, the dataset represents a rare and valuable source of real-world clinical practice information from actual post-landing operations.

In summary, we found that OI remains common after spaceflight and that current treatment, particularly IVF administration, varies widely in the absence of standardized protocols. These findings highlight the need for operationally practical, evidence-informed guidelines for managing OI during post-landing recovery. Developing such guidelines will be essential for reducing practice variability, improving astronaut safety, and provide basis for further research.

Declarations

Conflict of Interest:

None.

Funding Statement:

None.

Author Contribution

JP and LJKV both participated in the study design, data analysis, and preparation of the manuscript.

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Data Availability

All data supporting the findings of this study are available upon request pending review by NASA Lifetime Surveillance of Astronaut Health.

References

1. Yates, B. J. & Kerman, I. A. Post-spaceflight orthostatic intolerance: possible relationship to microgravity-induced plasticity in the vestibular system. *Brain Res. Brain Res. Rev.* 28, 73–82 (1998).

2. Jirak, P. et al. How spaceflight challenges human cardiovascular health. *Eur. J. Prev. Cardiol.* 29, 1399–1411 (2022).
3. Stenger, M. B. et al. *Risk of Orthostatic Intolerance During Re-exposure to Gravity*.
4. van Loon, L. M., Steins, A., Schulte, K. M., Gruen, R. & Tucker, E. M. Computational modeling of orthostatic intolerance for travel to Mars. *NPJ Microgravity* 8, (2022).
5. Jordan, J., Limper, U. & Tank, J. Cardiovascular autonomic nervous system responses and orthostatic intolerance in astronauts and their relevance in daily medicine. *Neurological Sciences* vol. 43 3039–3051 Preprint at <https://doi.org/10.1007/s10072-022-05963-7> (2022).
6. Goto, M. Physiological Changes in the Cardiovascular System During Space Flight – Current Countermeasures and Future Vision –. *Circ. Rep.* <https://doi.org/10.1253/circrep.cr-25-0096> (2025) doi:10.1253/circrep.cr-25-0096.
7. von Elm, E. et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J. Clin. Epidemiol.* 61, 344–9 (2008).
8. Hedge, E. T. et al. Implementation of exercise countermeasures during spaceflight and microgravity analogue studies: Developing countermeasure protocols for bedrest in older adults (BROA). *Front. Physiol.* 13, 928313 (2022).
9. JASP Team (2026). JASP (Version 0.96.0)[Computer software].
10. Lee, S. M. C., Feiveson, A. H., Stein, S., Stenger, M. B. & Platts, S. H. Orthostatic Intolerance After ISS and Space Shuttle Missions. *Aerosp. Med. Hum. Perform.* 86, A54–A67 (2015).
11. Tays, G. D. et al. The Effects of Long Duration Spaceflight on Sensorimotor Control and Cognition. *Front. Neural Circuits* 15, 723504 (2021).
12. Convertino, V. A. Mechanisms of microgravity induced orthostatic intolerance: implications for effective countermeasures. *J. Gravit. Physiol.* 9, 1–13 (2002).
13. Buckey, J. C. et al. Orthostatic intolerance after spaceflight. *J. Appl. Physiol.* (1985) 81, 7–18 (1996).
14. Keshavarz, B., Andrievskaia, P. & Berti, S. Individual-difference factors in visually induced motion sickness and vection: Findings from multiple studies on field dependence, age, and biological sex. *J. Vestib. Res.* 9574271251388972 (2025) doi:10.1177/09574271251388971.
15. Apfel, C. C. et al. Evidence-based analysis of risk factors for postoperative nausea and vomiting. *Br. J. Anaesth.* 109, 742–53 (2012).
16. Hahn, R. G. & Van Regenmortel, N. Is the NICE Guideline for maintenance fluid therapy in adults in hospital appropriate? *Clin. Nutr. ESPEN* 63, 113–120 (2024).
17. Arabi, Y. M. et al. European Society of Intensive Care Medicine clinical practice guideline on fluid therapy in adult critically ill patients. Part 1: the choice of resuscitation fluids. *Intensive Care Med.* 50, 813–831 (2024).
18. Mekontso Dessap, A. et al. European Society of Intensive Care Medicine (ESICM) 2025 clinical practice guideline on fluid therapy in adult critically ill patients: part 2-the volume of resuscitation

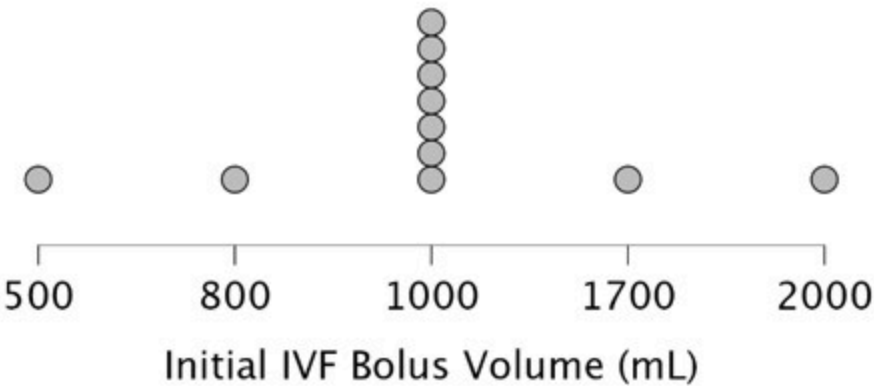
fluids. *Intensive Care Med.* 51, 461–477 (2025).

19. Smorenberg, A. & Groeneveld, A. B. J. Diuretic response to colloid and crystalloid fluid loading in critically ill patients. *J. Nephrol.* 28, 89–95 (2015).

20. Ciofani, G. et al. Pharmaceutical and biomedical challenges for crew autonomy in health preservation during future exploration missions. *Communications medicine* 5, 418 (2025).

Figures

A.



B.

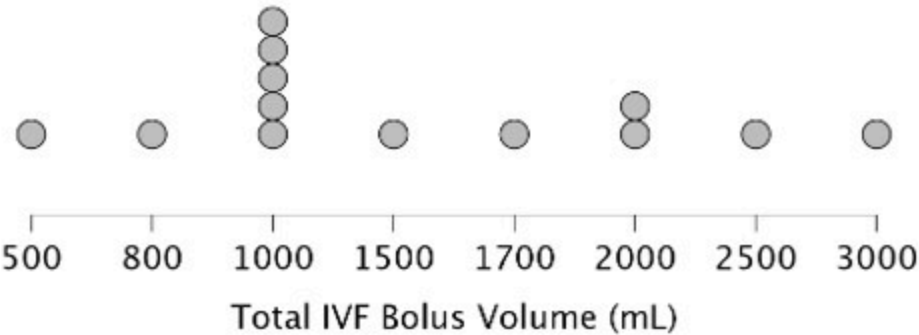


Figure 1

(A) Initial and (B) total intravenous fluid bolus volumes among astronauts receiving IVF

Supplementary Files

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