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NASA Risks of Decompression Sickness and Venous Thromboembolism during Spaceflight and Patent Foramen Ovale Implications

Outcomes of Working Group Meeting – August 2026

Compiled by:

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Invited Panel Members

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Dr. Caroline Fife – Chief Medical Officer, *Intellicure LLC*

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CSA = Canadian Space Agency
ESA = European Space Agency
JAXA = Japanese Aerospace Exploration Agency

Executive Summary

The purpose of this working group was to assemble a panel of experts to review the most recent data related to extravehicular activity (EVA) prebreathe testing and decompression sickness (DCS) events, venous thromboembolism (VTE) in-flight occurrences, and patent foramen ovale (PFO) implication as they relate to NASA's Artemis (lunar and beyond) missions. The recommendations from this working group are built upon and integrate the outcomes of the September 2024 Assessment of Patent Foramen Ovale (PFO) as Related to Decompression Sickness (DCS) in the Spaceflight Environment and During Ground Testing (NASA/SP-20240010473), the April 2026 NASA Risk of Venous Thromboembolism in Spaceflight Working Group (NASA/SP- 20260005258/REV1), and the updated DCS prevention standard reviewed by the DCS panel in NASA-STD-3001 Volume 2 Human Factors, Habitability, and Environmental Health (NASA-STD-3001 Vol 2 Rev F), with a specific focus on risk mitigation interventions such as PFO closure.

The following is a summary of the panel's recommendations:

VTE and PFOs in Spaceflight Risk Assessment

The panel discussed whether a PFO increases VTE risk in altitude or hypoxic environments.

> *The consensus was that the presence of a PFO is not considered a major risk factor for VTE formation, nor for complications from an embolism traveling from an initial formation site in the left internal jugular or cerebrum at normoxic or proposed hypoxic space habitats. No changes to astronaut selection criteria regarding PFOs are recommended with respect to VTE.*

Hypercoagulability at Altitude: It was noted that high altitude and hypoxia can increase hypercoagulability and VTE risk. However, studies of populations living at altitude equivalents that NASA is considering (< 8,000 feet) do not show clinically significant increases in VTE rates compared to sea level, despite some biomarker evidence of hypercoagulability. Studies looking at higher altitudes (> 8,000 feet) do indicate increased VTE rates, though studies involving healthy populations equivalent to astronauts are limited (Feng et al., 2026).

Blood Flow Dynamics: VTEs experienced in spaceflight have historically occurred in the internal left jugular and the cerebral sinuses; no lower extremity thromboses have been experienced in spaceflight to date. Due to the structure of the heart and the upper-body nature of thromboses seen in space, it was determined that a PFO does is not expected to significantly increase the risk of further complications from a VTE.

Specifically, blood flow from the inferior vena cava streams directly toward the interatrial septum and the fossa ovalis. Conversely, the crista interveniens directs superior vena cava (SVC) flow away from the interatrial septum. This flow away from a PFO further minimizes the relevance of a PFO when an embolism originates in the upper body (Borden, Coon, & Lang, 2012; Montrief et al., 2020).

PFO and DCS Risk

The panel evaluated whether a crew member with a PFO coupled with proposed DCS prebreathe protocols for Artemis faces an increased risk of a significant health event during a mission.

It was determined that a "small" PFO (Grade 1 or 2) does not pose a significant risk. There were mixed opinions on whether closing or screening out crew members with a "large" PFO (Grade 3 or above) significantly reduces the risk of a venous gas embolism (VGE) passing to the arterial side and causing a significant mission health event. The group did not recommend universal screening or exclusion of astronauts with large PFOs but emphasized the importance of risk mitigation through protocol design and ongoing data collection. If crews are assessed, they should be informed of their status and offered closure for a large PFO.

- **Evidence from Diving Data:** Diving literature indicates that a large PFO increases the risk of DCS by a factor of 5; however, the absolute risk of diving remains extremely low due to the use of established safe protocols. Translating diving data to "altitude" is difficult, as no definitive trials or studies have been conducted to determine the association between PFO and DCS at altitude (Kerut et al., 2001).
- **Paradoxical Embolism Risk:** A large PFO may increase the risk of a paradoxical embolism, but the absolute risk remains low. Current guidelines do not recommend routine closure unless there is a history of cryptogenic stroke or recurrent neurological DCS (Kottoor & Arora, 2018).
- **Protocol Efficacy:** Conservative protocols are considered effective in preventing DCS and may provide protection to individuals with small PFOs.

Assessment of DCS Risk through Venous Gas Emboli (VGE)

The panel evaluated whether VGE can be used to assess decompression stress and/or the risk of DCS at altitude in partial gravity with ambulation.

The consensus of the group is that there is no definitive link between bubble grades and the risk of DCS at altitude for prebreathe protocols involving partial gravity and ambulation.

VGE Predictive Value & Bubble Grading

The panel concluded that while minimizing bubbles is desirable, the predictive value of bubble scores for DCS remains uncertain, especially for lunar surface operations.

- The negative predictive value of VGE grading is high; the complete absence of bubbles is a strong indicator of low DCS risk.
- A high VGE (Grade 4) has a slightly positive predictive value for DCS; however, many individuals with high bubble grades remain entirely asymptomatic.
- The timing of bubble appearance during a scan (early vs. late) may help distinguish between intracardiac shunts (such as a PFO) and intrapulmonary shunts.

Left Ventricular Gas Emboli (LVGE) Findings

- Improved imaging technology has increased the detection rate of LVGE, making it a more common finding.
- While LVGE is measurable, the panel determined it is not clinically significant enough to warrant altering current protocols. However, the presence of LVGE could indicate an underlying atrial septal defect or PFO.

Panel Recommendations for Ground-Based Studies & Treatment

Ground-based studies should no longer remove subjects from research solely due to the presence of LVGE. Protocols should balance subject safety with population representativeness, and subjects must be fully informed of their LVGE status and any associated risks.

- **Safety Review:** Ground-based testing protocols should undergo a comprehensive review to confirm subject safety.
- **Treatment Efficacy:** The current treatment protocols for DCS should be formally tested to prove their efficacy.

Pre- and Post-EVA Pharmaceutical Usage

The panel assessed current pre- and post-EVA pharmacological strategies for preventing DCS and managing pain. The discussion critically examined the use of aspirin for DCS mitigation and assessing the risks of concurrent VTE prophylaxis with apixaban. Furthermore, the panel identified a need for definitive clinical guidelines regarding the prevention and treatment of EVA-related pain and inflammation to avoid contraindicated drug interactions.

The panel concluded that clear clinical guidance is required regarding medication use for all crewmembers prior to Extravehicular Activities (EVAs). Specifically, protocols must address the use of aspirin for Decompression Sickness (DCS) prevention and pain relief. Additionally, guidance is needed for the pre- and post-EVA use of analgesics (acetaminophen, ibuprofen, naproxen, celecoxib), as these medications have the potential to mask DCS symptoms.

- **Aspirin for DCS Prevention:** NASA currently administers aspirin prior to EVAs to mitigate DCS risk. Animal studies indicate that nitrogen bubbles interact with thrombocytes, causing adhesion and activation that can contribute to microvascular obstruction and DCS-related damage (Westerweel, Fjen, & Van Hulst, 2013). Because aspirin has potent antithrombotic effects on platelet function, it may reduce this microvascular obstruction. However, while organizations like the Divers Alert Network (DAN) recognize its theoretical benefit (Buzzacott & Chimiak, 2017), the practice is supported primarily by limited animal studies rather than human clinical trials.
- **Bleeding Risks and Drug Interactions:** Clear guidelines are necessary to address the concurrent use of aspirin and prophylactic apixaban (used for Venous Thromboembolism [VTE] prevention), as combining them significantly increases bleeding risks. Furthermore, if traditional NSAIDs (such as ibuprofen and naproxen) are used alongside preventive aspirin, they can competitively bind to the COX 1 enzyme, reducing aspirin's protective antiplatelet efficacy while further elevating the risk of gastrointestinal and general bleeding.
- **Pain Management Recommendations:** For managing pain associated with spacesuits and EVAs, the panel suggests acetaminophen as the first line option. Celecoxib may be considered as a secondary option for targeted inflammation and pain relief before escalating to other NSAIDs.

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