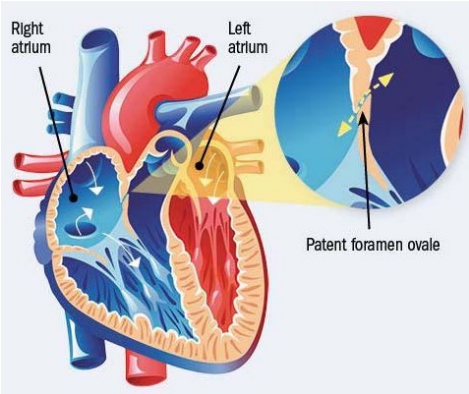
NASA-STD-3001 Medical Technical Brief

Patent Foramen Ovale (PFO)

OCHMO-MTB-011

Executive Summary

Patent foramen ovale (PFO) is a congenital heart defect consisting of a shunt between the right and left atrium of the heart. All humans are born with a PFO however 75% of the population permanently fuse PFOs during the first 2 years of life. The remaining 25% have a PFO that remains open with varied size shunt, 6% have a hole that has a large diameter (2mm) (Hagen, 1984). PFOs are usually harmless, and patients are unaware of their presence. The risk a PFO poses is that emboli gas can pass from the right to left atrium and bypass the normal lung filtration of the venous emboli which normally prevents passage to the atrial system, allowing emboli migration to the body and brain. This can potentially cause neurological degradation or stroke. PFO risk is elevated in persons exposed to unusual pressure changes which increase atria shunting including underwater divers, high altitude pilots, and astronauts. This medical technical brief defines PFO physiology, the risks present, diagnosis, and treatment options that help reduce the risks associated with PFOs.



Source: Harvard Health

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev C

[V1 3003] In-Mission Preventive Health Care
[V1 3004] In-Mission Medical Care
[V1 5001] Medical Training
[V1 5002] Crewmember Training
[V1 5003] Crew Medical Officer Medical Training

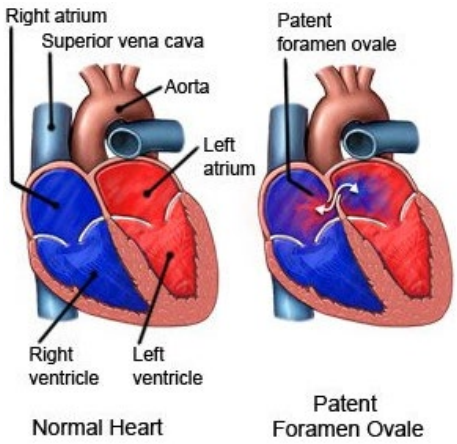
NASA-STD-3001 Volume 2, Rev F

[V2 6002] Inert Diluent Gas
[V2 6003] O2 Partial Pressure Range Crew Exposure
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure
[V2 6007] Rate of Pressure Change
[V2 6008] Decompression Sickness (DCS) Risk Identification
[V2 6009] Decompression Sickness Treatment Capability
[V2 6017] Atmospheric Control
[V2 6022] Atmospheric Monitoring and Alerting Parameters
[V2 7043] Medical Capability
[V2 9053] Protective Equipment
[V2 11100] Pressure Suits for Protection from Cabin Depressurization
[V2 11032] LEA Suited Decompression Sickness Prevention Capability
[V2 11036] Suited Atmospheric Monitoring and Alerting

Reference NASA/SP-20240010473: Assessment of Patent Foramen Ovale (PFO) as Related to Decompression Sickness (DCS) in the Spaceflight Environment and During Ground Testing

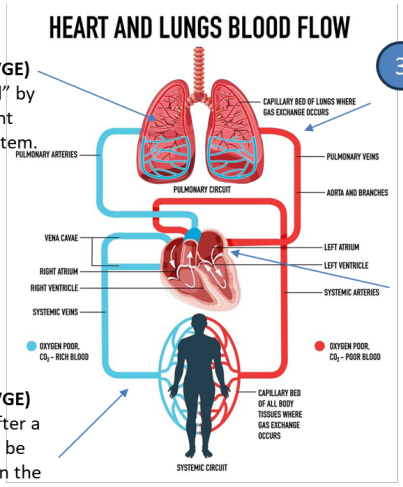
Physiology

A patent foramen ovale (PFO) is one of the most common types of congenital heart defects. During pregnancy, the fetal lungs are non-functional and receive oxygenated blood from the placenta. As the heart develops, a hole/shunt (PFO) located between the right and left atrium of the heart is present allowing blood to pass, directly bypassing the lungs. Post-natal increases in left atrial pressure usually force the inter-septal valve against the septum and permanently fuse within the first 2 years of life (Saary & Gray, 2001). In 25% of the population the fuse is not established, and the PFO remains open usually undetected and harmless. The concern with PFOs is that right to left shunt between atria can allow venous emboli to pass from the right atrium (venous) to the left atrium (arterial), bypassing the normal lung filtration of venous emboli which prevents passage to the arterial system. Without filtration, bubbles in the arterial system may travel and lead to a neurological event such as a stroke.



Source: Drugs.com

Any activity that increases the right atrium/venous pressure over the left atrium/arterial pressure such as a Valsalva maneuver, abdominal compression, underwater diving, spaceflight, or anything that can alter pressure may further enable blood and/or emboli across a PFO/shunt.



2 **Venous Gas Embolism (VGE)**
Most VGE can be "filtered" by the lungs, which prevent passage to the arterial system.

3 **Arterial Gas Embolism (AGE)**
VGE that are not filtered by the lung are arterial gas emboli (AGE). AGE put the astronaut at risk of vascular blockages and resulting ischemic damage to brain or other organs

4 **Patent Foramen Ovale**
PFO is a right to left shunt between the atria (hole in the heart), venous emboli gas (VGE) may pass from the right atrium (venous) to the left atrium (arterial).

1 **Venous Gas Embolism (VGE)**
Any remaining Nitrogen after a prebreathe protocol can be release when the crew is in the suit at a lower pressure.

Adapted from Heart and Lungs Blood Circulation Diagram: Vector Stock Images

Venous Gas Embolism (VGE)	Arterial Gas Embolism (AGE)
Origin: bubbles form from dissolved gas in tissues during decompression	**Origin:** originates from lung over-expansion or from right to left shunting of a VGE
Pathway: venous return → pulmonary circulation	**Pathway:** system arterial circulation
Clinical Effects: often asymptomatic if low bubble load but high load can lead to coughing and shortness of breath	**Clinical Effects:** acute, severe symptoms such as stroke-like neurological, loss of consciousness, seizures, cardiac ischemia
Severity: subclinical or mild, can become serious if high bubble load	**Severity:** potentially catastrophic, often life threatening

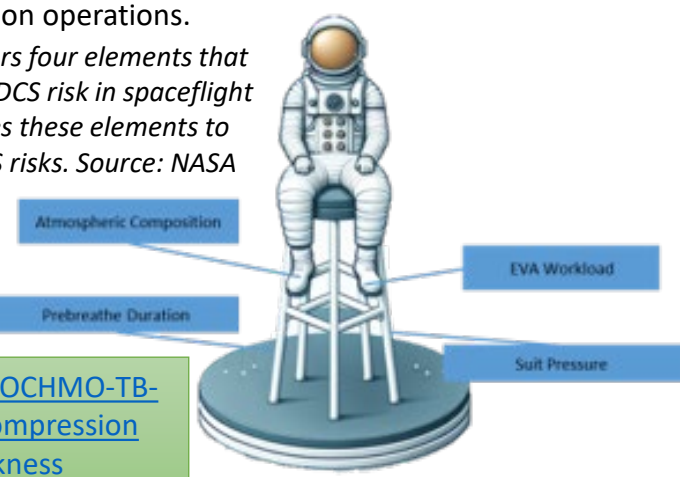
Pathophysiology

Spaceflight Risks for PFO

The risk of PFO in spaceflight presents during extravehicular activities (EVAs) when astronauts perform mission tasks outside the spaceflight vehicle wearing a pressurized suit at a lower pressure than the cabin pressure. PFO can increase the risk of decompression sickness (DCS) as the right to left shunting of venous gas emboli (VGE), increases risk of potentially harmful embolism migration. DCS mitigation protocols are based on strategies to reduce bubbles causing systemic nitrogen load. These are implemented through the combination of habitat environmental parameters, EVA suit pressure, and breathing gas procedures (prebreathe protocols) to achieve safe and effective mission operations.

NASA presently classifies DCS into two categories:
Type I DCS is less severe, typically leads to musculoskeletal symptoms including pain in the joints or muscles, or skin rash. **Type II DCS** is more severe and commonly results in neurological, inner ear, cardiopulmonary symptoms, and cutaneous Marmorata rash.

NASA considers four elements that contribute to DCS risk in spaceflight and balances these elements to mitigate DCS risks. Source: NASA



Reference OCHMO-TB-037 Decompression Sickness

Neurological symptoms may include numbness, paresthesia, or altered sensation such as tingling, muscle weakness, an impaired gait, or difficulty walking, problems with physical coordination or bladder control, paralysis, or a change in mental status such as confusion or lack of alertness. Inner-ear symptoms may include ringing in the ears, known as “tinnitus”, hearing loss, vertigo or dizziness, nausea/vomiting, and impaired balance. Cardiopulmonary symptoms include dry cough, chest pain behind the sternum or breastbone, and breathing difficulty, also known as “dyspnea.” (Denoble & Holm, 2015).

Past NASA Decompression Protocols for Prevention of DCS
NASA has never experienced a Type II event in spaceflight

In-Suit 4-Hour Prebreathe
Astronaut breathes 100% O_2 in the spacesuit at 14.7 psia for 4 hours.

Campout Protocol
Significantly reduces the required in-suit prebreathe duration by having EVA crewmembers “camp out” in the ISS airlock at 10.2 psia, 26.5% O_2 during the night prior to their EVA. For various operational reasons, the time at 10.2 psia is limited to 8 hours and 40 minutes.

Exercise Protocol
Intense, short exercise regimen at 14.7 psia while breathing 100% O_2 combined with in-suit prebreathe at 10.2 psia.

In-Suit Light Exercise (ISLE) Protocol
A longer period of mild exercise in the EMU. The ISLE protocol shares many steps with the exercise prebreathe protocol but differs in that 40 minutes are spent breathing 100% O_2 by mask followed by a 20-minute depressurization to 10.2 psia.

Currently, NASA does not disqualify astronaut candidates who have a PFO. In accordance with OCHMO-STD-100.1A, all astronaut candidates are assessed for a PFO during their first annual exam. Despite the high prevalence of PFO in the general population (approximately 25%), and the relatively common occurrence of venous gas bubbles in diving and altitude exposures, the incidence of Type II DCS in diving or with altitude is remarkably low (Saary & Gray, 2001). This issue is continually being evaluated, especially if long duration/ Mars travel may require additional restrictions.

Risk Evaluation

PFO Symptoms and Presentation

- Most people that have a PFO are unaware and remain symptom-free throughout their lifetime.
- PFOs have been linked to several medical conditions including migraine headaches, sleep apnea, fatigue, and shortness of breath but not with a definitive causal effect and are usually not tested.
- The most serious symptoms of PFO are cryptogenic Transient Ischemic Attack (TIA) or stroke. When an otherwise healthy, often active person presents with a TIA or stroke, medical personnel will consider doing diagnostic testing to see if a PFO could be the explanation.

Stroke Numbers	
U.S. annual stroke incidence	795,000
Stroke hospitalizations <65 years	35%
Percentage of strokes <60 years that are cryptogenic	30-40%
Cryptogenic strokes with PFO present	40-50%

Source: CDC Stroke Facts 2024, American Stroke Association

PFO presence does not guarantee causality. PFO evaluations can help determine likelihood of a PFO as a contributing factor. When a patient < 60 years presents with a TIA or stroke of undetermined origin (cryptogenic stroke) they are often evaluated to determine possible contributors that can help treatment decisions.

RoPE Score The risk of paradoxical embolism score (RoPE score) is a clinical prediction tool used to estimate the likelihood that a PFO is the cause of a cryptogenic stroke. It considers other causal factors, as those are eliminated the chance that the PFO was the contributor increases. High RoPE (≥7): Greater likelihood that PFO is causal; may consider PFO closure after multidisciplinary discussion. Low RoPE (≤7): PFO likely incidental; closure benefit uncertain.

Source: MDCalc Cardiovascular Risk Calculator

PFO special population – other groups considered for PFO evaluation include participants in altered pressure activities such as underwater diving, high altitude flying, sky diving and spaceflight participants.
Pressure changes can increase the risk of bubble, clot, or embolism, shunting from right to left atrium increasing the risk they can travel towards the brain and cause neurological symptoms.

Criterion	Points
Age	18-29 yrs = 5; 30-39 yrs = 4; 40-49 yrs = 3; 50-59 yrs = 2; 60-69 yrs = 1; >70 yrs = 0
No history of hypertension	+1
No history of diabetes	+1
No history of prior stroke or TIA	+1
Non-smoker	+1
Cortical infarct on imaging	+1

Score	Approx. % PFO-attributable
0-3	~0%
4	38%
5	34%
6	62%
7	72%
8	84%
9-10	88%

In addition to the RoPE score, PFO size can be a risk factor and is associated with increase of causality of PFO. Physicians use the RoPE score in addition to bubble study evaluation information to help inform PFO decisions.

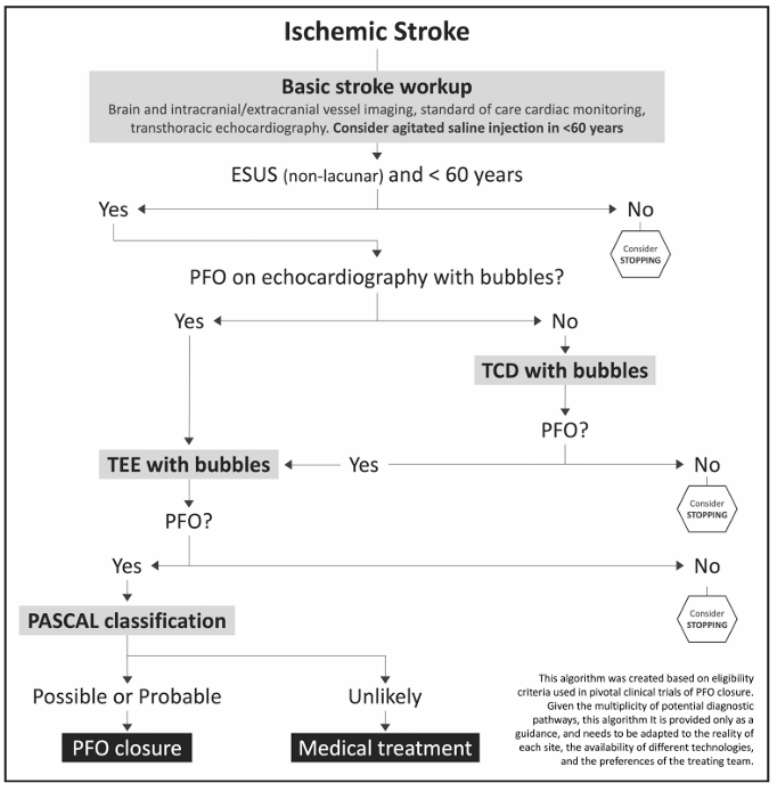
Detection & Classification

The PFO-Associated Stroke Causal Likelihood (PASCAL) classification system combines the RoPE score and anatomical criteria from echocardiography (large shunt, atrial septal aneurysm) to classify PFO as the "probable," "possible," or "unlikely" cause of otherwise cryptogenic stroke.

PASCAL Classification System

High RoPE score (≥7)	High-risk PFO feature (LS and/or ASA)	PFO-related stroke
Absent	Absent	Unlikely
Absent	Present	Possible
Present	Absent	
Present	Present	Probable

Source: Sposato et al. (2024)



PFO size increases the probability of causality but is not determinative.

- **Probable** Large PFO + large shunt + ASA + high RoPE score → highest likelihood of causal relationship. These patients have a 90% relative reduction in recurrent ischemic stroke with closure.
- **Possible** 2 scenarios: (1) high-risk PFO and a RoPE score <7, (2) low-risk PFO (absence of a large shunt and ASA) and a RoPE score ≥7. POSSIBLE patients have a 62% relative reduction in recurrent stroke with closure
- **Unlikely** Small PFO + low shunt + low RoPE score. more likely incidental, not significant difference between closure and medical therapy.
- Younger patients with few vascular risk factors and large shunts have the strongest causal association.

Source: Sposato et al. (2024)

PFO evaluation assists physicians to determine best treatment options once PFO is detected. In patients categorized as PASCAL "probable", there was a 90% decreased relative rate of recurrent ischemic stroke after PFO closure at 2 years (hazard ratio, 0.10 [95% CI, 0.03-0.35]; absolute risk reduction 2.1% [95% CI, 0.9%-3.4%]). PASCAL "unlikely" patients (older patients with vascular risk factors and no high-risk PFO anatomical features) did not have a lower recurrent stroke rate with PFO closure.
Source: Wang (2025)

Detection & Classification

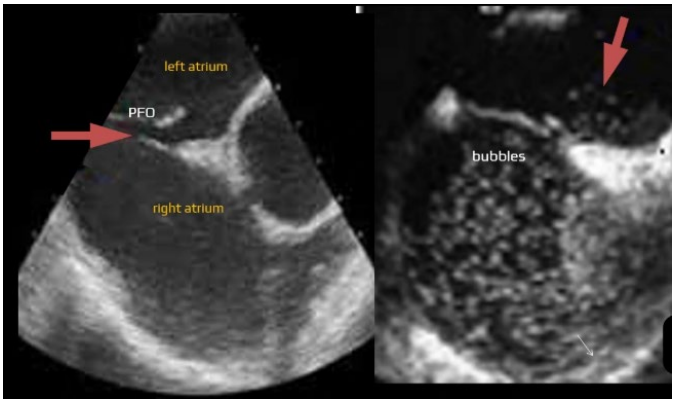
If an event or symptoms occur and PFO is suspected, or for screening processes for certain high-risk patients (diving, spaceflight), a bubble study is used to determine presence and size of PFO if present.



TTE
Source: Circle Health Group



Agitated saline
Source: Ji & Seoung (2023)



Bubble study echocardiogram, bubbles passing through PFO
Source: Phillips.com

Agitated saline bubble study The bubble study is a noninvasive test that allows observation of blood flow through the heart. It consists of a regular echocardiogram (an ultrasound that shows the heart structure) accompanied with an injection of agitated saline solution into the right atrium, which in an unaffected heart the bubbles will travel to the right ventricle and are diffused in the lungs. If a PFO is present, the bubbles will travel from the right atrium to the right ventricle showing evidence of a shunt or hole in the heart. The practitioner will apply pressure to the abdomen or encourage the patient to Valsalva to increase pressure that will allow the bubbles to be more visible across the PFO. If a PFO is detected through a bubble test, the patient may undergo more invasive diagnostics to further confirm PFO and determine size. Other tests including TTE and TEE also use bubbles to identify PFO.

0	**no microbubbles in the left atrium (no left shunt)**
1	Small shunt with <20-30 microbubbles in the left atrium
2	Moderate shunt with > 20-30 bubbles, moderate filling of left atrium
3	Large shunt with > 25-30 microbubbles or complete opacification of the left atrium



Source: Zhang et al. (2020)

Standard PFO Classification System
PFO size is determined during contrast echocardiography bubble study given with agitated saline and evaluated to see if bubbles pass through the PFO shunt. Larger amounts of bubbles pass with larger shunts and are associated with higher risk. *Source: Kent et al. (2021), Mas et al. (2017), & Søndergaard et al. (2017)*

A bubble study is considered a very safe procedure. General discomfort, including at the injection site are rare and usually minimal. Proper technique and patient selection maintain procedure safety.

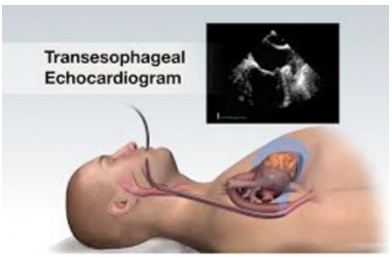
Spaceflight participants are assessed for PFO during their first astronaut candidate examination. PFO size is determined to inform treatment decisions. Current evidence indicates that patients with moderate/large PFOs or atrial septal aneurysm (ASA) have a higher risk of stroke recurrence and more likely to benefit from PFO closure. *Source: Sposato (2022)*

Detection & Classification

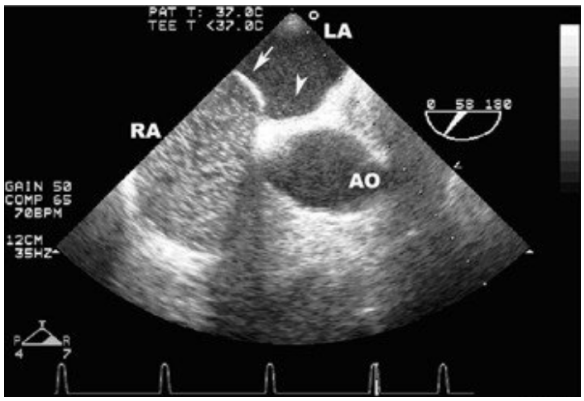
Transthoracic Echocardiogram (TTE) A noninvasive method using a probe on the skin of the chest, similar to a standard ultrasound echocardiogram. TTE can be used with contrast and/or agitated bubbles. TTE can identify PFO or other cardiac pathologies, however views may be limited due to distance from transducer and image quality may be suboptimal in some patients. The TTE result sensitivity may be limited in patients with high BMI compared to a transcranial doppler (TCD) (Liou, 2015). The risk of TTE procedure is low, and the most common adverse effects is discomfort from the IV/injection and potential skin irritation from the transducer transmission gel. TTE is often used by cardiologists as the initial diagnostic test due to low risk, ease of use, low cost, and diagnostic ability (Van der Giessen, 2020; Fordyce, 2022).

Transesophageal echocardiogram (TEE) Gold standard for PFO diagnosis in patients with stroke, with a weighted sensitivity of 89% relative to autopsies or inspection during cardiac surgery. TEE places a probe with an ultrasound transducer into the esophagus to assess structure and function of the heart. The transducer is located closer to the atria, allowing higher frequency ultrasound than TTE resulting in higher resolution images. One limitation is that the transducer may interfere with the patient's ability to perform an adequate Valsalva maneuver which can help identify a PFO.

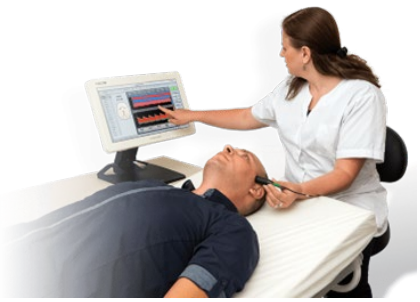
TEE may require light sedation and is time consuming, more costly, and more invasive compared to either TCD or TTE, including risk of esophageal tear during procedure (0.03-0.09%) and reaction to sedating medication. TEE has been considered the diagnostic modality of choice for many institutions to more definitively rule out or further characterize a PFO after an initial assessment via TTE.



Source: Medmovie.com



TEE showing PFO during a bubble study. Source: Gupta et al. (2007) Echocardiography



Transcranial Doppler. Source:

Transcranial Doppler (TCD) A noninvasive measure of cerebrovascular function using a portable doppler ultrasound transducer held in place with a headband over the temporal window used to measure blood flow to and within the brain. A PFO can be detected with TCD by injecting agitated saline in a peripheral vein and observing if any microbubbles appear either at rest or during a Valsalva maneuver. Patients with absent temporal bone window may not be able to use TCD as an effective diagnostic tool. TCD is low risk, with potential side effects including mild discomfort during testing, discomfort from the IV/injection, skin irritation from transducer transmission gel, and/or dizziness.

Pros & Cons: TTE is painless, quick, easily accessible, cost effective, and does not require sedation, however image quality may be lower and body fat or physiology can interfere with detection. TEE gives high resolution detailed images, however it requires sedation and is invasive.

Treatment Guidelines

Once a patient has a detected PFO, they will determine with physician assistance whether to receive treatment. The decision to treat PFO necessitates a serious conversation between a patient and provider to determine the pros and cons of PFO treatment. Common considerations include patient health, history, current lifestyle/activity level, and consideration of symptoms, especially if stroke occurred. Occupational restrictions or concerns are also considered, for example whether divers should proactively screen and treat PFO as their profession increases risk of DCS and embolism if untreated. When a PFO is identified after stroke or TIA, antiplatelet therapy is commonly used with closure considered for selected patients (i.e., larger PFO). Closure has shown superiority in reducing recurring stroke risk in major comparative studies.

Trial	Follow-up	PFO Closure	Antiplatelet	Anticoagulant
CLOSURE I (2012)[14]	~2 yrs	0.0%/yr	3.0%/yr	0.8%/yr
PC Trial (2013) [26]	~4.1 yrs	0.5%/yr	~1.0%/yr*	Included in medical therapy
RESPECT Initial (2013) [7]	~2.6 yrs	0.5%/yr	~1.1%/yr*	Included in medical therapy
RESPECT Long-Term (2017) [30]	5.9 yrs	0.39%/yr	~1.07%/yr*	Included in medical therapy
REDUCE (2017) [32]	3.2 yrs	0.39%/yr	1.71%/yr	None
CLOSE (2017) [23]	5.3 yrs	0.0%/yr	1.22%/yr	0.31%/yr
DEFENSE-PFO (2018) [37]	2.8 yrs	0%/yr	4.4%/yr	No separate arm

Risk of recurrent stroke
** In PC and RESPECT, the control group was "medical therapy" and included both antiplatelet and anticoagulant treatment. DEFENSE-PFO enrolled only very high-risk PFO patients (large shunt and/or atrial septal aneurysm), explaining the unusually high event rate*

Treatment	PFO Treatment Risks
Observation	Ongoing risk of recurrent paradoxical embolism
Antiplatelet therapy	Major bleeding risk generally <1% per year
Anticoagulation	Major bleeding ~1-3% /yr year depending on agent and patient factors
Percutaneous PFO Closure	Atrial fibrillation 3-7% (device specific, greatest in first 45 days, 59% resolve within 2 weeks); procedural complications ~1-3%
Surgical Closure	Highest procedural morbidity; rarely used

Source: Sposato et al. (2024)

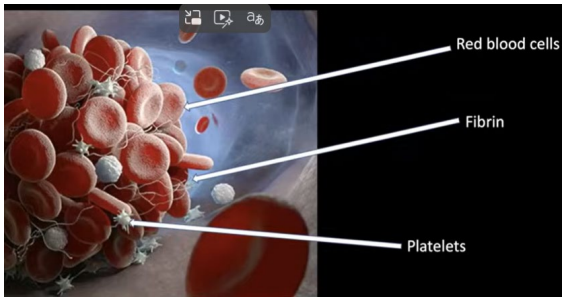
Astronauts who are identified as having a PFO make treatment decisions in tandem with flight surgeons which include considering any additional risks, size of PFO, and spaceflight demands including duration of flight and activities including EVA's and surface activities.
Spaceflight treatment considerations: Medication antiplatelet/anticoagulation therapy contain a bleeding risk that astronauts need to consider as some spaceflight activities including EVAs may pose complications associated with bruising and bleeding further increased by medication therapy.

Treatment Guidelines

Pharmaceuticals

Thrombus or clot is a soft clump that forms when certain parts of blood thicken leading to a semi-solid mass/clot. Clots can be a normal part of the healing process and naturally dissolve, but sometimes they form and move about the body increasing risk of vessel blockage leading to damage or disease. PFOs can allow these clots to pass from the left atrium and be carried to the brain and periphery, increasing risk of stroke or TIA. Antithrombotic medications can help reduce clot formation.

Arteries carry blood from the heart to periphery, arterial clots lead to stroke, heart disease, and peripheral artery disease. Artery clots contain more platelets than fibrin and respond better to antiplatelet medications. Veins carry blood from periphery to heart and venous clots lead to deep vein thrombosis and pulmonary embolisms. Venous clots contain more fibrin than platelets and respond to anticoagulant therapy that target different clotting factors to decrease the formation of fibrin.



Source: CHOC Health

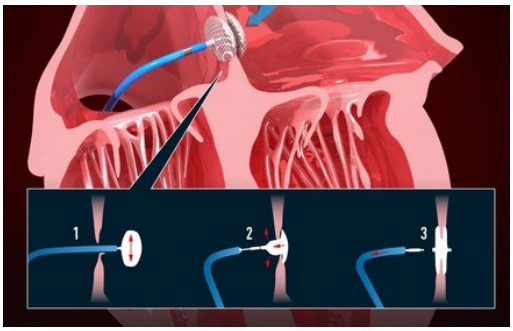
Pharmaceutical	Estimated recurrent stroke risk	Risks (listed in approximate %)	Typical Patient
Aspirin - Antiplatelet	~1.1-1.8%/year *CLOSE, REDUCE, RESPECT Trials (23, 32, 30)*	Major bleeding 0.5 – 1%/yr, GI bleeding 0.3-1.39%/yr, Intracranial hemorrhage 0.03-.25%/yr. *(4, 6)*	First-line therapy after cryptogenic stroke when closure is not performed.
Aspirin+Clopidogrel Antiplatelet	~0.9-1.5%/year *CLOSE, REDUCE, RESPECT Trials (23, 32, 30)*	Major Bleeding 1.33%/yr, Intracranial hemorrhage 0.73%/yr *(5, 11)*	Short-term use after selected neurologic or cardiovascular events
Clopidogrel Antiplatelet	~1.1-1.7%/yr as general antiplatelet rate *CLOSE, REDUCE, RESPECT Trials (23, 32, 30)*	GI bleeding 1.04%/yr, Intracranial hemorrhage)0.17%/year. *(6)*	Patients' intolerant of aspirin or requiring stronger antiplatelet effect
Apixaban, Rivaroxaban, Dabigatran Warfarin Anticoagulant	Apixaban 0.97-1.27%/yr, Warfarin 1.0-1.6%/yr *ARISTOTLE Trial (16)*	DOAC (Rivaroxaban) vs Wafarin, Major bleeding 3.11% vs 3.36%/yr, Intracranial Hemorrhage 0.3% vs 0.74%/yr, Major GI bleed 1.51% vs 1.02%/yr. *(9)*	Patients with DVT, PE, hypercoagulable disorders, atrial fibrillation, or high clot burden

Astronaut treatment of PFO is the same as terrestrial use of medications, however flight surgeons need to account for any additional risk that spaceflight poses. For example, astronauts at times take aspirin and/or anti-inflammatory medications to treat inflight pain or inflammation. These medications can increase bleeding risk and will need to be carefully considered if antiplatelet or anticoagulant medications are being used for PFO treatment.

Treatment Guidelines

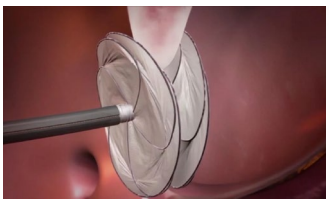
PFO Closure (Transcatheter)

Closure of a PFO is performed using a transcatheter device fed into the heart via the femoral vein. During this procedure, a transeptal sheath travels through the PFO into the left atrium, an umbrella-like structure opens left atrium side of the septum, and then the right atrium side, creating a seal over the PFO so blood can no longer traverse the septum (the closure device does not create a seal immediately after the procedure, the endothelium must migrate over the device to accomplish a true seal). The patient is usually prescribed oral anticoagulation for 3 – 6 months post-closure. Complication rates with PFO closure are dependent on the device utilized and skill of the clinician. Complications reported by various trials include atrial fibrillation (3-7%) cardiac tamponade (0.4%), device migration/embolization (0.5%), infective endocarditis (0.2%), and stroke (0.4%). These potential complications are rare, but all should be mentioned in the patient consent process for device closure. *Gonnah et al., (2022)*.



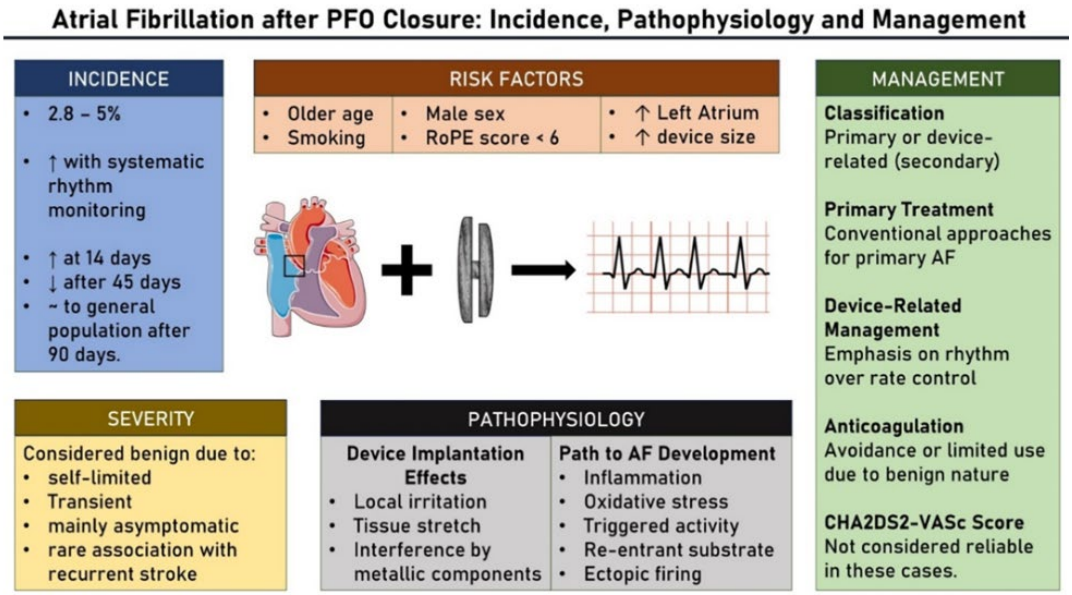
Transcatheter PFO closure device.
Source: The Heart & Vascular Centre

In a randomized open-label trial of 980 patients with PFO and history of cryptogenic ischemic stroke, long-term (>5 years) follow-up found that closure was associated with a 45% lower rate of recurrent ischemic strokes than among patients who received medical therapy alone. Closure reduced the relative risk of recurrent cryptogenic stroke by 70% compared to medical therapy. Closure has shown to decrease cryptogenic stokes in multiple trials, with 62% relative risk reduction in favor of closure. *Saver et al. (2017); Turc et al. (2018)*.



Gore PFO occlude device
Source: Diagnostic & Interventional Cardiology

Atrial fibrillation is a rare side effect after PFO closure. Most episodes occur within the first 45 days and resolve on their own but may cause discomfort and necessitate follow up.



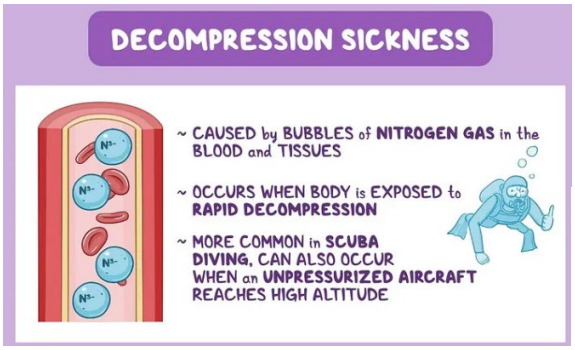
Source: American Heart Association

Pathophysiology

PFO Risks in the Diving Community

The diving community is one population that may be affected by a PFO. Undersea divers experience pressure changes which can cause a buildup of nitrogen bubbles. A PFO can increase risk that these bubbles will travel directly into the arterial bloodstream leading to embolization in organs and tissues. The PFO in divers may let gas bubbles from venous blood pass the arterial side, increasing risk of DCS. *Divers Alert Network (DAN).*

DCS is caused by a decrease in pressure surrounding the body. Divers experience nitrogen gas compression during ascent; the nitrogen bubbles enlarge and travel throughout the body. The enlarged bubbles can migrate to lungs, joints, or other body areas causing blockages, discomfort, neurologic symptoms, and potentially death. The known risk factors for divers are deep or long dives, cold water, heavy exercise at depth, and rapid ascents.



Source: Osmosis.org

Conservative diving includes reducing dive times, limiting number of dives, use of nitrox with dive planning tools, lengthening safety stops, more shallow dives, and avoid heavy exercise and unnecessary lifting soon after dives.



Guidelines for Patent Foramen Ovale and Diving

Divers Alert Network

Most standard guidelines have a stratified approach that suggest recreational and commercial divers do not need to be screened for PFO, as serious DCS is rare and the link between PFOs and DCS is not clear. The DAN Guidelines for Patent Foramen Ovale recommends “Routine screening for PFO at the time of dive medical fitness assessment is not indicated. Consideration should be given to testing for PFO when there is a history of more than one episode of decompression sickness (DCS) with cerebral, spinal, vestibulocochlear or cutaneous manifestations.”

At the NASA Neutral Buoyance Laboratory (NBL), astronauts are trained to conduct suited/pressurized extravehicular activities (EVA) underwater to simulate a microgravity environment. Support divers also participate in underwater activities to observe and assist astronauts during training. Since 2015, 79,568 dive hours (including astronauts and support divers) have been conducted with a total of 5 events of DCS recorded. Divers are not screened for PFOs at this time.

Back-Up

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 1 Revision C

[V1 3003] In-Mission Preventive Health Care All programs shall provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA), individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. In-mission preventive care includes, but is not limited to: (see NASA-STD-3001 Volume 1 Rev C for full technical requirement)

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, individual crewmember needs, clinical practice guidelines, flight surgeon expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses consider the needs and limitations of each specific vehicle and design reference mission (DRM) with particular attention to parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, and behavioral care, are to include, but are not limited to: (see NASA-STD-3001 Volume 1 Rev C for full technical requirement).

[V1 5001] Medical Training Medical training shall be provided to crewmembers, flight surgeons (FSs), mission control support staff, and other ground support personnel (GSP).

[V1 5002] Crewmember Training Beginning with the astronaut candidate year, general medical training, including, but not limited to, first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of space flight, psychological training, and supervised physical conditioning training shall be provided to the astronaut corps.

[V1 5003] Crew Medical Officer Medical Training Crewmembers who have received a mission assignment as a Crew Medical Officer (CMO) shall be provided with detailed and specific medical training, including but not limited to, health issues, space physiology, behavioral health, medical procedures, medical equipment, toxicology, and countermeasures.

NASA-STD-3001 Volume 2 Revision F

[V2 6002] Inert Diluent Gas Cabin atmospheric composition shall contain at least 30% diluent gas (assuming balance oxygen).

[V2 6003] O2 Partial Pressure Range Crew Exposure The system shall maintain inspired oxygen partial pressure (PIO2) in accordance with Table 6.2-1—Inspired Oxygen Partial Pressure Exposure Ranges.

[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure The system shall maintain the pressure to which the crew is exposed to between 34.5 kPa < pressure ≤ 103 kPa (5 psia < pressure ≤ 15.0 psia) for indefinite human exposure without measurable impairments to health or performance.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 2 Revision F

[V2 6007] Rate of Pressure Change For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.

[V2 6008] Decompression Sickness (DCS) Risk Identification Each program shall define mission unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence:

a. DCS ≤ 15% (includes Type I or isolated cutis marmorata).

b. Grade IV venous gas emboli (VGE) ≤ 20%.

c. Prevent Type II DCS.

[V2 6009] Decompression Sickness Treatment Capability The system shall provide DCS treatment capability.

[V2 6017] Atmospheric Control The system shall allow for local and remote control of atmospheric pressure, humidity, temperature, ventilation, and ppO2.

[V2 6022] Atmospheric Monitoring and Alerting Parameters The system shall display real-time values for pressure, humidity, temperature, ppO2, and ppCO2 data to the crew locally and remotely.

[V2 7043] Medical Capability A medical system shall be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.

[V2 9053] Protective Equipment Protective equipment shall be provided to protect the crew from expected hazards.

[V2 11100] Pressure Suits for Protection from Cabin Depressurization The system shall provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of Micrometeoroids and Orbital Debris (MMOD) or complex vehicle maneuvers).

[V2 11032] LEA Suited Decompression Sickness Prevention Capability LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

[V2 11036] Suited Atmospheric Monitoring and Alerting Suits shall monitor suit pressure, ppO2, and ppCO2 and alert the crewmember when they are outside safe limits.

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