NASA-STD-3001 Medical Technical Brief

Spaceflight Associated Neuro-ocular Syndrome (SANS)

OCHMO-MTB-001

Executive Summary

Spaceflight Associated Neuro-ocular Syndrome (SANS) refers to a constellation of ocular findings including optic disc edema, posterior globe flattening, chorioretinal folds, and hyperopic shifts in refractive error observed in astronauts during and following long-duration spaceflight. SANS etiology is not certain, but altered gravity and fluid shifts resulting in venous congestion and intracranial pressure elevations are the most likely causes. The concerns associated with signs and symptoms of SANS are decrements in vision that can affect in-flight crew capability and task performance as well as long-term eye health risks that could result from eye and brain structural changes that develop during spaceflight. In this technical brief we discuss the pathophysiology, and countermeasures being used and studied in order mitigate these risks.

NASA astronaut Tim Kopra conducts a self-exam as part of the Ocular Health investigation on the ISS.

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev C

[V1 3001] Selection and Recertification
[V1 3002] Pre-Mission Preventive Health Care
[V1 3003] In-Mission Preventive Health Care
[V1 3004] In-Mission Medical Care
[V1 3016] Post-Mission Health Care
[V1 3018] Post-Mission Long-Term Monitoring
[V1 4020] In-Mission Nutrient Intake
[V1 5001] Medical Training
[V1 5002] Crewmember Training
[V1 5003] Crew Medical Officer Medical Training
[V1 6008] Crew Health Operations Concept Document
[V1 6009] Medical and Crew Health Technical Requirements Document

NASA-STD-3001 Volume 2, Rev D

[V2 6001] Trend Analysis of Environmental and Suit Data
[V2 6004] Nominal Vehicle/Habitat Carbon Dioxide
[V2 6022] Atmospheric Monitoring and Alerting Parameters
[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation
[V2 7100] Food Nutrient Composition
[V2 7043] Medical Capability
[V2 7045] Medical Equipment Usability

Physiology

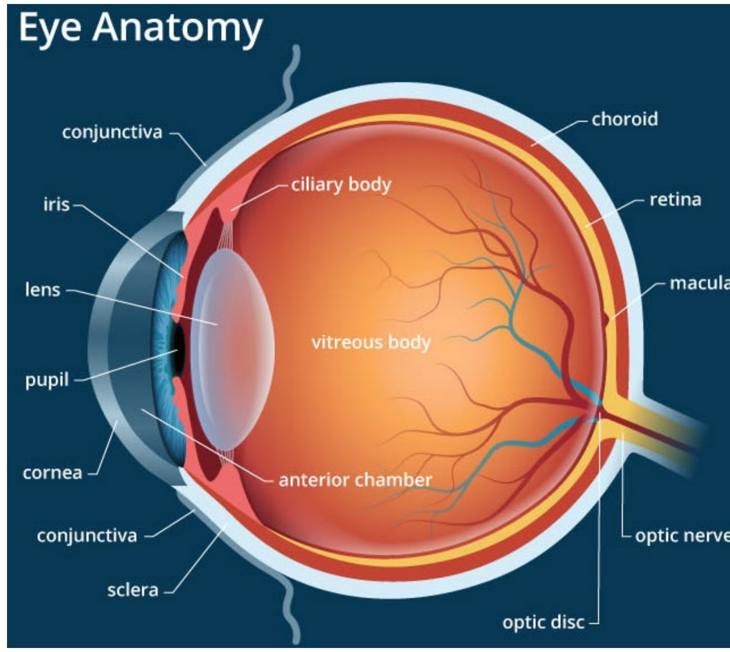


Image Source: All About Vision

Eye Anatomy

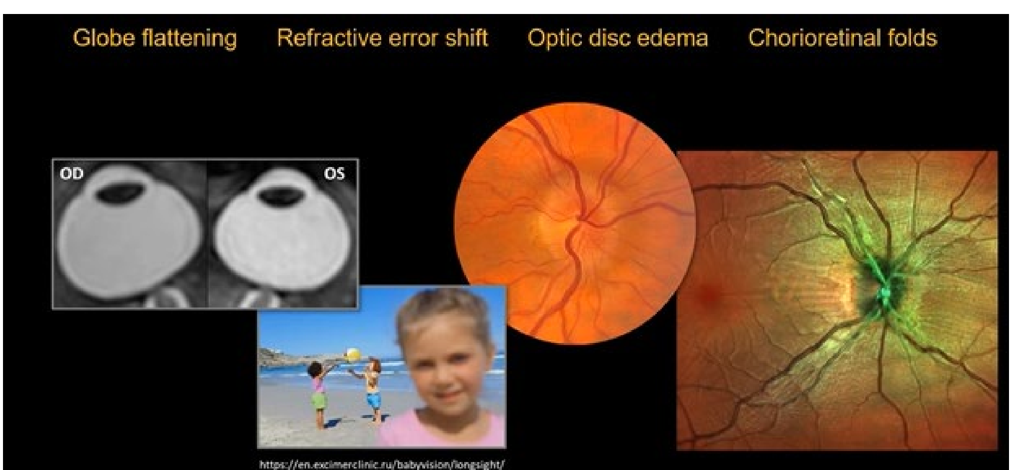
The etiology of SANS is uncertain; one theory is that SANS is thought to be a result of fluid shifts during gravity changes causing increased fluid and pressure to the head and eye, leading to physiological changes (optic disc edema (ODE), globe flattening (GF), and chorioretinal folds that can result in vision changes (hyperopic vision shifts, refractive vision decrements). The main concerns of SANS are increased risk of vision decrements in-flight, negatively affecting crewmember performance and risk of irreversible vision decrements causing long term vision changes/loss.

Potential Causes of SANS

- Increased intracranial pressure due to fluid shifts caused by microgravity loss of hydrostatic pressure, venous congestion, or limited cerebrospinal fluid drainage.
- Nutrition: cyanocobalamin and folate-dependent one carbon pathway variability.
- Brain ventricular absorption changes and intracranial compartmentalization.
- Impaired sleep which may reduce lymphatic/glymphatic clearance from the brain and eye.

Potential Risk Factors

- Space/microgravity environment
- Nutritional changes
- CO_2 air pockets
- Repeat flyers
- Increased mission duration and severity of SANS signs may increase risk for potential in-mission and long-term health consequences
- Crowded/small optic nerve head

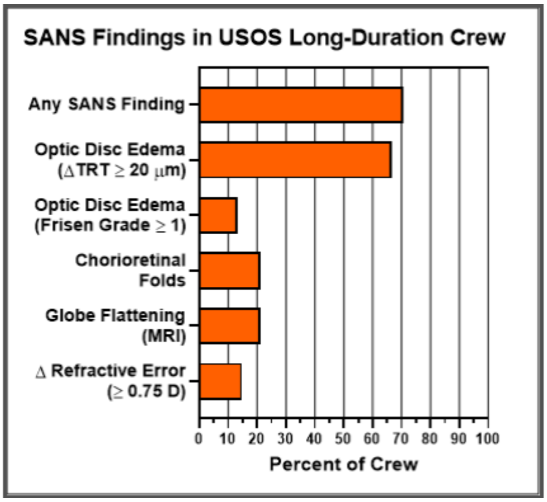


Symptoms of SANS. Image Source: NASA

Idiopathic Intracranial Hypertension (IIH) has some similar characteristics to SANS, as both present with optic disc edema; however, they share more differences than similarities. Mildly elevated ICP caused by gravity-induced fluid shifts is one hypothesis for the potential cause of SANS.

Pathophysiology

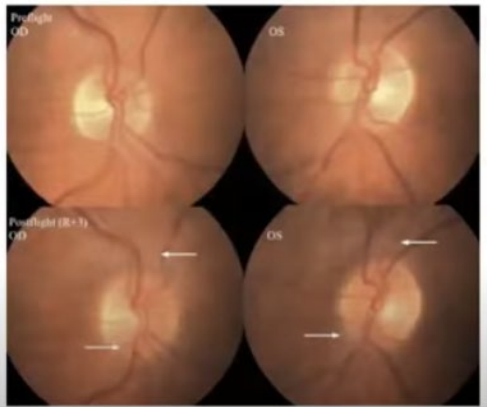
The primary concern of SANS is that the changes in ocular structure may lead to uncorrectable vision changes either during or after a spaceflight mission, affecting crew capability/task performance and possible long term health decrements..



Percent of crewmembers that present with ocular findings of SANS in which data exist. USOS, US Orbital Segment ΔTRT, change in global total retinal

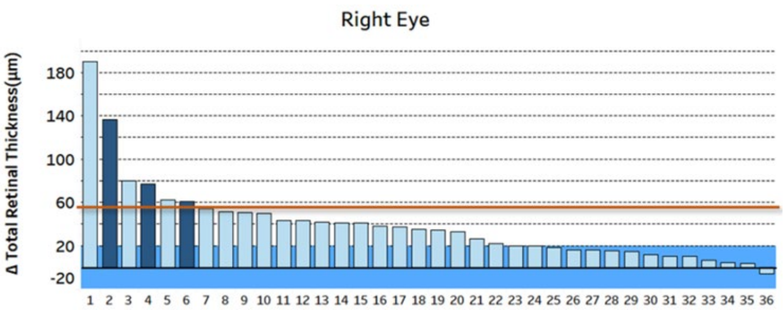
70% of crew are reported to have one or more signs of SANS and 18% of crewmembers are diagnosed with clinically concerning SANS during long duration spaceflight. To date, no crew have reported uncorrectable vision changes following spaceflight.

Optic Disc Edema (ODE) Unilateral or bilateral swelling of the intraocular portion of the optic nerve, associated with highest risk to crewmember vision. It can be measured by direct clinical observation using fundoscopy and photography (see right), Optical Coherence Tomography (OCT), and in more severe cases, MRI and ultrasound. Images are gathered pre-flight, in-flight and post-flight, see below for example.



ODE images right: (Top) Pre-flight images of the right and left optic discs. (Bottom) Post-flight images of the optic nerve head showing in more detail the extent of the edematous optic disc margins and glutting of the superior and inferior nerve fiber layer axons. Mader et al. (2011)

Total Retinal Thickness (TRT) refers to swelling of the optic disc that spills over into the retina next to it, causing that retina to thicken.



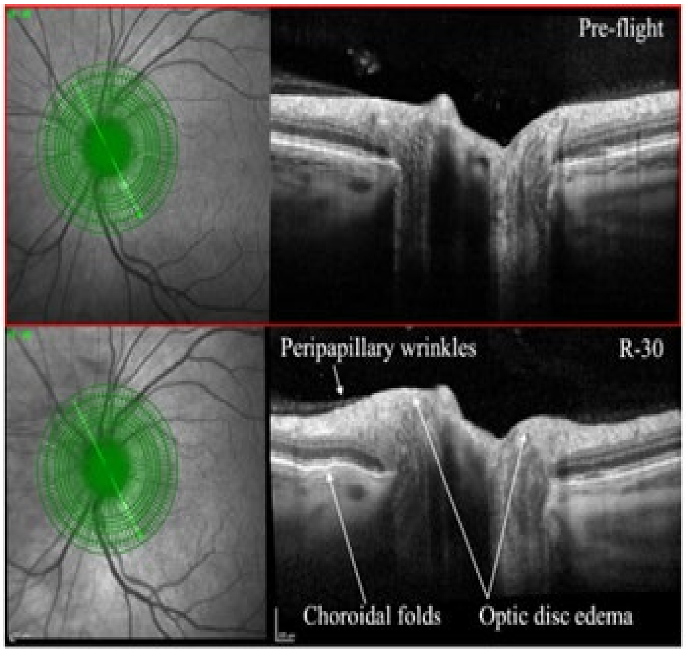
OCT data is presented in pre- to in-flight changes in peripapillary TRT measured by OCT. ΔTRT of ±19.4 µm (blue bands) indicates the range of normal measurement variability; greater than this is the earliest sign of ODE. The dark vertical bars represent eyes with ODE of Frisen grade of 1, as detected by fundoscopy. The orange line represents a ΔTRT of 55 µm.

Idiopathic Intracranial hypertension (IIH) is similar to SANS and present with ODE and ICP. Terrestrial IIH has different characteristics than SANS and fluid shifts caused by gravity-induced ICP is the leading hypothesis for the cause of SANS.

Pathophysiology

Chorioretinal folds (CF) refer to folding of the superficial retinal layers (i.e., retinal folds), retina's basement membrane (i.e., choroidal folds), and/or edges of the optic nerve head (i.e., peripapillary wrinkles). Terrestrially they are caused when unusual force is placed on the retina, causing folds. When located near the fovea CF can cause distorted or reduced visual acuity. Choroidal folds are present in approximately 25% of long-duration crewmembers. Moderate to severe choroidal folds near the fovea have been detected in long duration crewmembers. Persistent progressive folds during missions can potentially degrade vision and increase risk of debilitating uncorrectable vision defects. To date no permanent losses in vision have been detected in any crewmembers.

Chorioretinal folds are detectable by fundoscopy or OCT. Crewmembers are monitored pre-flight, in-flight, and post-flight for changes and any associated vision decrements.



Pre-flight (top) and 30 days prior to return (R-30 bottom), comparison on OCTwith R-30 showcasing peripapilliary wrinkles, choroidal folds, and optic disc edema. Image: HSRB NASA

Multicolor imaging pre-flight, 30 days prior to returning to Earth (R-30), and 4 days after return (R+4). Choroidal folds are noted in R-30 and R+4. Possible protrusion of optic nerve head is visible at R-30 and R+4.

Frisén scale Describes stages of optic disc swelling (grades 0-5). It is the standard classification method for terrestrial ODE, and is used internationally in clinical and research practice. Indications for post-flight lumbar punctures in SANS cases are: >/= Frisen grade ODE as determined by fundoscopy, and >/= 55um average increase in peripapillary total retinal thickness (TRT) in either eye by OCT.

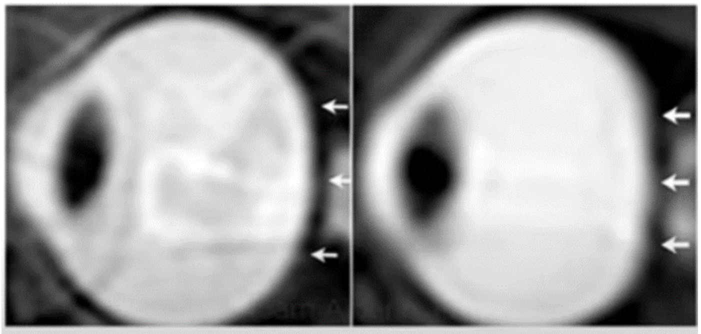
Grade	Definition/Findings
0	Normal optic disk
I	Minimal papilledema: subtle C-shaped halo of disk edema with a normal temporal disk margin
II	Low-degree papilledema: circumferential halo of disk edema
III	Moderate papilledema: obscuration of one or more segments of the major blood vessels leaving the disk
IV	Marked papilledema: partial obscuration of a segment of major blood vessel on the disk
V	Severe papilledema: partial or total obscuration of all blood vessels on the disk

SANS overview and Clinical Practice Guideline NASA 2020

Laurie et al. determined an increase in TRT of >19.4 µm marks the earliest signs of ODE in SANS. *SANS Overview and Clinical Practice Guideline, NASA 2020.*

Pathophysiology

Globe Flattening Posterior globe flattening (GF) refers to shortening of the eye during spaceflight. Approximately 25% of long-duration crewmembers experience GF centered at the insertion point of the optic nerve into the globe. If severe, this can cause a hyperopic shift in refractive error and vision decrements. Globe flattening is usually associated with force pressing on the eye from behind (e.g., retrobulbar tumor). Globe flattening is measured pre- and post-flight using an MRI, and in-flight using ultrasound (less reliable than terrestrial MRI). Larger GF has been associated with ODE and is being monitored to determine vision decrements and associated changes. Long term crewmember health monitoring via MRI shows persistent GF has appeared in crewmembers greater than 7 years after flight.

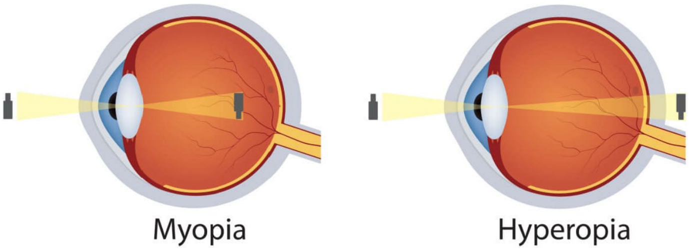


Posterior Globe flattening. *Source: J. Ann & E. Kim (2015).*

Visual acuity shift example. *Source: NASA*

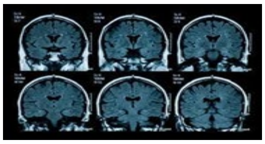
Hyperopic vision shifts Spaceflight associated alterations in visual acuity have been identified over the past 40 years. 29% of short duration crewmembers and 60% of long duration crew have reported vision degradation. Mader et al. 2011 study showed post-mission shift ranging from +0.5 to +2.0 change in diopter measurement. Hyperopic refractive shift changes in visual acuity occur when focal point is adjusted due to GF. Vision degradation risk increases the longer you are in space. All crewmembers post-flight vision has been correctable to 20/20 or better with updated prescription. Hyperopic changes in refractive error occur when the retina's location shifts. Potential causes of hyperopic shift include ODE, GF, choroid thickness, and changes to the optical components of the eye.

Refractive error is a measurement of lens power needed to correctly focus light on the retina of the eye. Myopia (near-sightedness) occurs when light focuses in front of the retina and is corrected with ‘minus’ lenses, and hyperopia (far-sightedness) is when light focuses behind the retina and is corrected with ‘plus’ lenses. Myopic patients experience blurred distance vision, whereas hyperopic patients may experience eyestrain and/or blurred near vision if their accommodative system (i.e., system that focuses the eye by changing the shape of the crystalline lens) is not able to compensate for their hyperopic refractive error.



Source: All About Vision (2022)

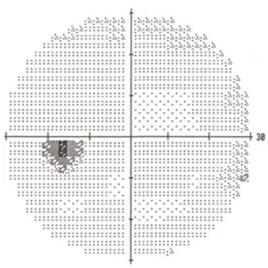
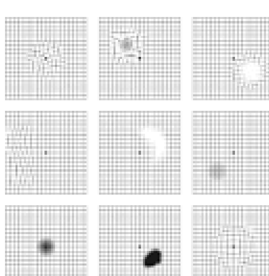
Monitoring & Diagnostics

Equipment/Diagnostic Method	Image Example	Purpose/Use	Schedule
Comprehensive Eye Exam		Variety of eye examinations given including eye charts, OCT, ultrasound, and others to assess eye functioning and health	Pre- and post-flight
Fundoscopy		Fundoscopy assesses the gross structural changes in the optic nerve head and retina; detects ODE, CF	Pre-, in-, and post-flight
Optical Coherence Tomography (OCT)		OCT is used to assess the retina, choroid, and optic nerve head anatomy; measures ODE, CF	Pre-, in-, and post-flight
Ultrasound		Ultrasound assesses structural changes within/posterior to eye; measures in-flight globe flattening, optic nerve head protrusion, and other ocular defects	Pre-, in-, and post-flight
MRI		Eye MRI is used to detect structural changes in the eye	Pre- and post-flight

Primary SANS/Ocular Tests	Pre-flight	On-orbit			Post-flight
		FD30	FD90	R-30	
3T MRI – Head & Orbits	X	–	–	–	X
Comprehensive Eye Exam	X	–	–	–	X
Visual Field	X	Not yet on-orbit			X
Vision Screening – VA, Amsler grid, Survey	X	X	X	X	X
Retinal Photography – "Fundoscopy"	X	X	X	X	X
Optical Coherence Tomography	X	X	X	X	X
Ocular Ultrasound	X	X	X	X	X
Tonometry – Intraocular Pressure	X	X Note: ESA only; ACI otherwise	X	X	X

Example eye testing schedule. *Source: NASA*

Monitoring & Diagnostics

Equipment/Diagnostic Method	Image Example	Purpose/Use	Schedule
Ocular Biometry		Measures axial length of the eye. Quantifies pre- to post-flight shifts in retinal position, correlating with shifts in refractive error"	Pre- and post-flight
Visual Acuity Test		Visual Acuity Tests and Visual Field Tests assess the optical fidelity functional state of the eye	Pre-, in-, and post-flight
Visual Field Test			Will be deployed on future ISS mission
Lumbar Puncture		Direct measurement of cerebrospinal fluid (CSF) pressure. Measures CSF accompanying ODE. CSF >18 cm considered high normal, CSF > 25cm requires treatment	Post-flight
Amsler Grid			Pre-, in-, and post-flight

Monitoring & Diagnostics

Equipment Training

SANS is a known risk to spaceflight, therefore monitoring begins at crew selection. Training to operate SANS diagnostic devices occurs prior to spaceflight; however, it may be months before this training is actually used. Crewmembers are trained to identify SANS symptoms and to use detection and monitoring equipment. Crew are trained in SANS equipment: OCT, fundoscope, and ocular ultrasound.

<u>Training Schedule</u>

Pre-flight:

Nominal schedule ocular training begins 2 years before flight. Most pre-flight is hands on training with devices prior to flight. Some crewmembers may have more specialized training than others.

Ocular training includes:

- Fundoscopy – total of 2.5 hours across 2 sessions
- Tonometry – 1.5 hours to one crew designated as SANS specialist
- Ocular ultrasound – 1 hour
- OCT – 2.5 hours across 2 sessions
    - First session is within 12 months of launch, second session is within 3 months prior to launch

In-flight:

- Nominal schedule for 'Eye Weeks', which consists of 2-3 days (FD 30, 90, and R-30) at a time of monitoring and testing including OCT:
    - 1 month into mission
    - 1 month prior to return
    - During 6-month flights, OCT operator tests 3 times FD 30, 90, and R-30
    - Additional testing can be performed as clinically indicated at any point during mission

Ground assistance:

On ISS, in-flight crew receive assistance from ground with monitoring equipment.

- Ground based remote guider — person who has trained crew how to use equipment, this person is the only person in the room who can speak directly with crew with advice, suggestions, and guidance to use equipment.
- Subject Matter Expert (SME) — monitors two displays: 1) cabin view of subject and operator; 2) data to review for clinical requirements.
- Biomedical Engineer (BME) — in room and online to interact and guide data collections.

MED B Evaluation

Medical Evaluation Documents (MED) Volume B – Pre-Flight, In-Flight, and Post-Flight Medical Evaluation Requirements for Long-duration ISS Crewmembers
Ocular assessments are performed pre-flight, in-flight, and post-flight, as crewmembers have presented with significant changes in ocular structure and function in-flight and post-fight.

Pre-flight	In-flight	Post-flight
18-21 months prior: MRI brain and orbits, visual acuity (distance and near), refraction (manifest and cycloplegic), Amsler grid, pupil reflexes, extraocular muscle balance, biomicroscopy, dialated fundoscopy, retinal photography, tonometry, OCT, optical biometry 6-9 months prior: 2-D imaging ultrasound	Ocular questionnaire, visual acuity, Amsler grid, fundoscopy, 2-D imaging ultrasound, OCT (high-resolution). Threshold visual fields (measurement equipment being deployed in calendar year 2024. Additional testing as clinically indicated.	R+1/3 days: Ocular questionnaire, visual acuity, refraction, threshold visual fields, Amsler grid, pupil reflexes, extraocular muscle balance, fundoscopy,retinal photography, tonometry, OCT, Optical biometry, 2-D imaging ultrasound, MRI brain and orbits – special visual impairment and intracranial pressure protocol Additional testing as clinically indicated.

[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:
Requirement has 18 bullets, SANS specific information located in bullet m as seen below
m. Spaceflight Associated Neuro-Ocular Syndrome (SANS) periodic monitoring, and prevention with to-be-determined countermeasures (to be validated by research in the coming years).

[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: *Requirement has 22 bullets, SANS specific information located in bullet g as seen below*
g. Capability to provide deployed crewmembers with optical correction (e.g., glasses) with increased levels of power to mitigate SANS-induced changes in refractive error.

From: NASA-STD-3001 Volume 1

Reference Data

Clinical Practice Guideline

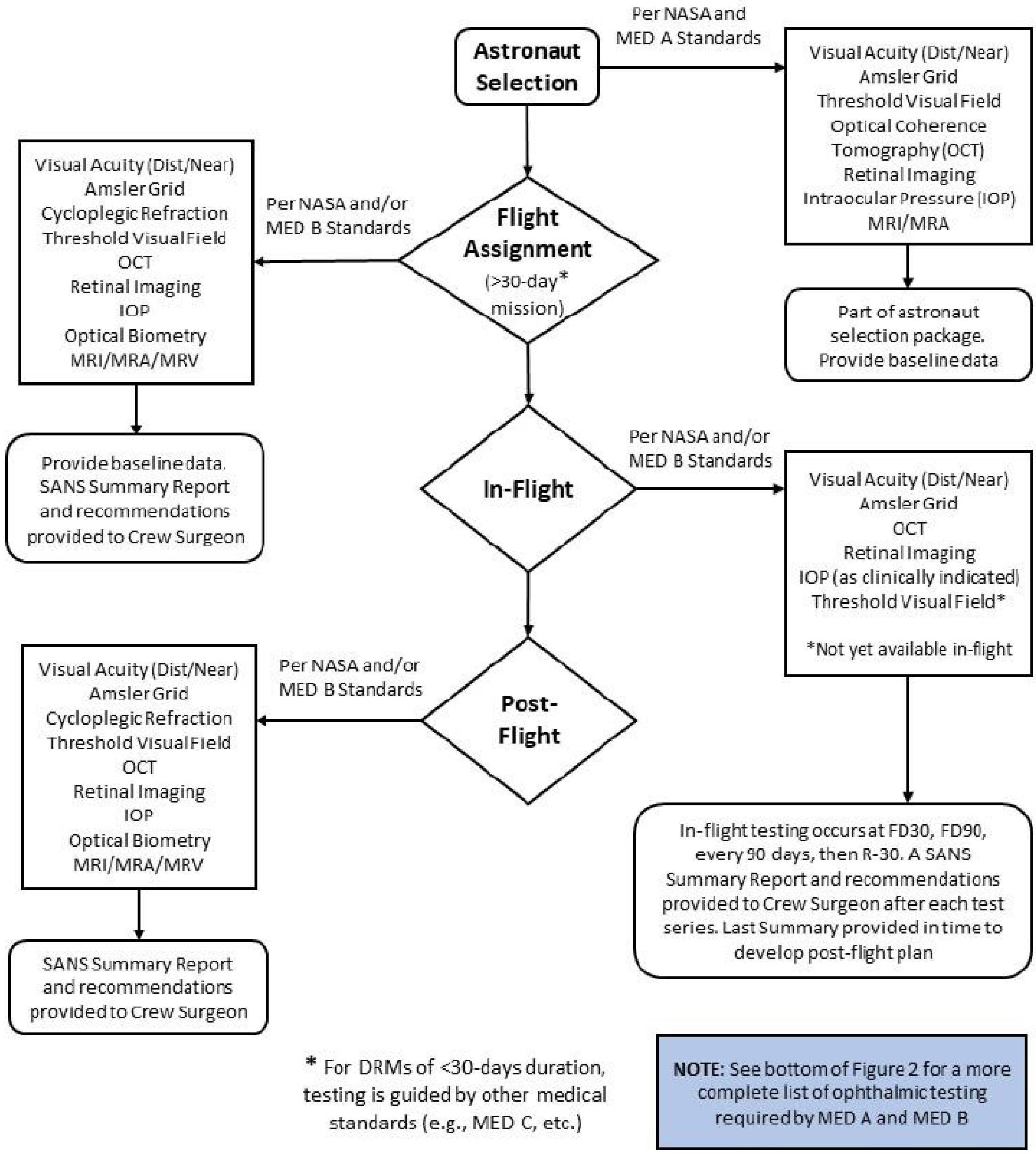


Figure 1: SANS Testing Overview

Reference Data

Clinical Practice Guideline

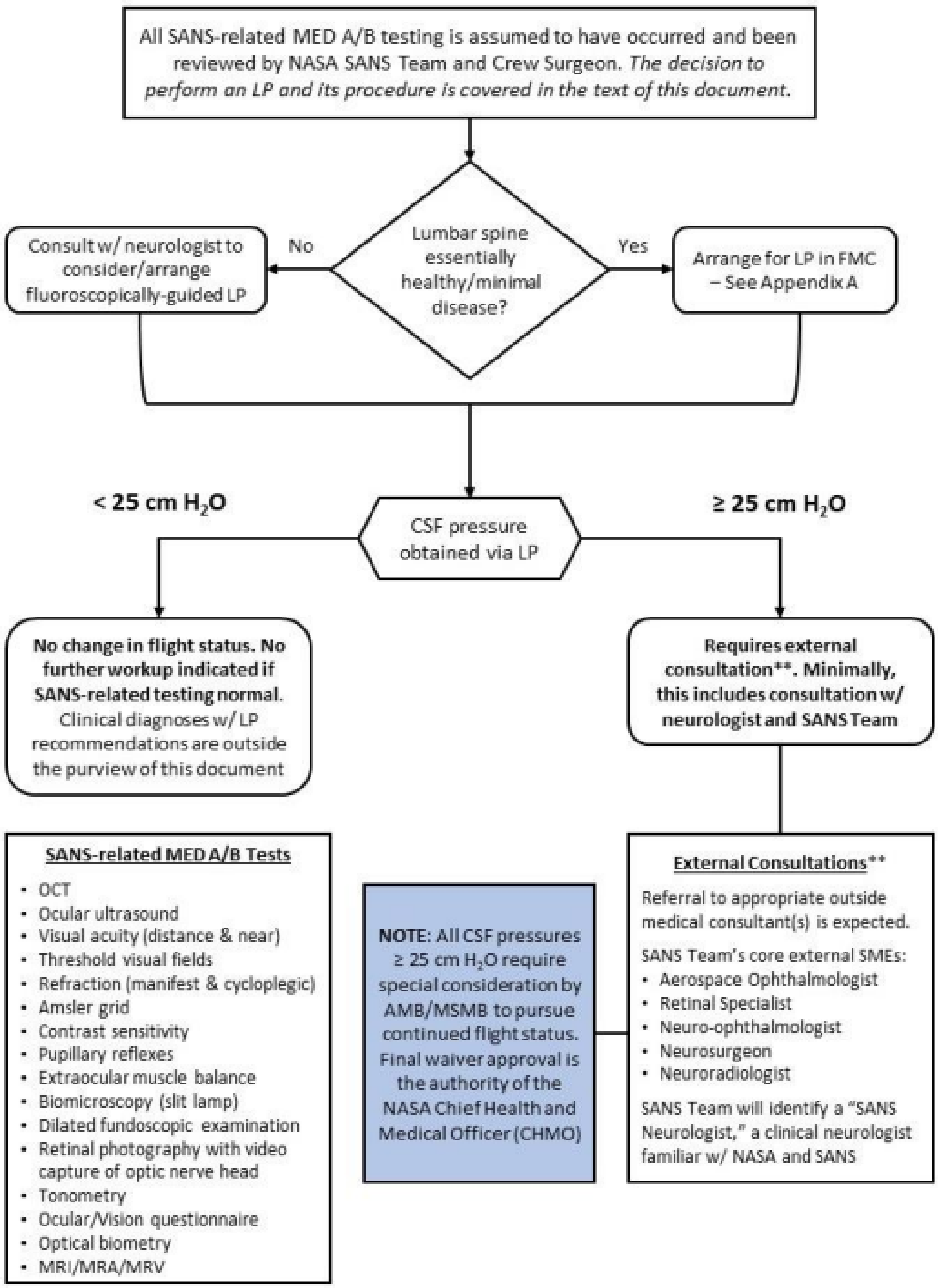
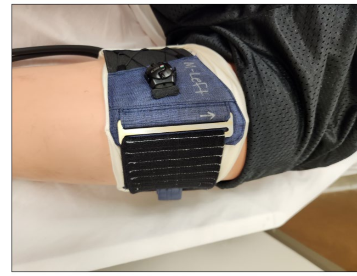


Figure 2: Cerebrospinal Fluid (CSF) Pressure Considerations and Guidance

Countermeasures & Treatment



Lower Body Negative Pressure Under consideration as a preventive countermeasure for fluid shift effects and SANS. Thigh cuffs may reduce fluid shifts and improve venous congestion and ICP changes.

Supplements/Nutrition Crewmembers can be given B vitamins (B-complex) in-flight, which are currently being studied for their effects on SANS including; affecting homocysteine pathways and improving microvascular function and reduce edema.

Medications No medications are currently proven to mitigate SANS, but efforts are ongoing. Potential medications are primarily aimed at lowering ICP (e.g., acetazolamide, which reduces ICP in terrestrial IIH patients).

Space Anticipation Glasses Used to help crewmembers with in-flight vision changes due to hyperopic shifts. All crew fly with at least 3 pairs of prescription lenses of varying power to help compensate for vision decrements in-flight.

"All CSF pressures ≥ 25 cm H_2O require special consideration by the Astronaut Medical Board (AMB)/ Multilateral Space Medicine Board (MSMB) to pursue continued flight status. Final waiver approval is the authority of the NASA Chief Health and Medical Officer (CHMO)." *NASA HSRB 2022*

Table 2 Emerging countermeasure strategies for decreasing the risk of spaceflight associated neuro-ocular syndrome (SANS)

Emerging countermeasure strategies for spaceflight associated neuro-ocular syndrome (SANS)	Rationale
Lower body negative pressure	Draw fluid from cephalad region towards the lower body
Goggles (increased intraocular pressure)	Increase translaminar pressure gradient that is reduced during spaceflight
B Vitamin supplementation	Relatively low B vitamin status in astronauts with ophthalmic changes
Venoconstrictive thigh cuffs	Reduce cephalad fluid shift
Identifying genetic risk factors	Certain risk alleles are associated with developing SANS
Artificial gravity (centrifugation)	Maintain hydrostatic pressure to prevent cephalad fluid shift

Ong, Tarver, Brunstetter, Mader, Gibson, & Mason (2023)

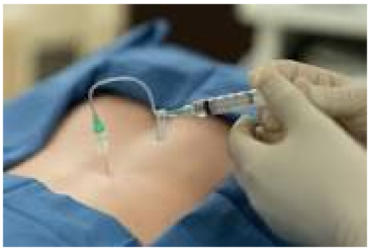
Countermeasures & Treatment

Elevated Intracranial Pressure

The pathogenesis of SANS ODE is unknown. Terrestrially, the significance of ICP on SANS remains unclear. However, based on the collection of SANS pathophysiology (i.e., ODE, chorioretinal folds, globe flattening, and hyperopic shifts), it is reasonable to hypothesize that ICP may be mildly elevated in SANS, but ICP measures have not been made during spaceflight so no definite in-flight conclusions can be made.

- Treatment of spaceflight-associated elevated ICP in an astronaut will occur on a case-by-case basis since we do not yet have adequate experience to give clear and well-tested treatments. Generally, post-flight CSFOP ≥25 cm H_2O should be given treatment consideration, particularly in the presence of new-onset optic disc edema and/or scotoma.
- For more serious cases of suspected ICP, lumbar punctures are given. Indications for post-flight lumbar punctures in SANS cases have 2 requirements: ≥ 1 Frisen grade ODE in either eye, as determined by fundoscopy, and/or ≥ 55 µm average increase in peripapillary TRT in either eye, as determined by OCT.

Lumbar puncture consists of a needle inserted into the space between two lumbar bones (vertebrae) to remove a sample of cerebrospinal fluid. A lumbar puncture is performed to determine if the pressure of the CSF is elevated.



Medications are currently being considered as a countermeasure to SANS. Of these medications, acetazolamide (Diamox) is the only one available onboard the ISS, but side effects limit the scenarios where it may be considered. Other potential SANS medications are listed below.

Medication	Usage	Side Effects
Diamox	Interfering with the sodium pump in the ciliary body, reducing the osmolality of aqueous humor, lowering the osmotic gradient and, thereby, aqueous volume. This reduces IOP and improves optic perfusion pressure.	Nausea, fatigue, diarrhea, vomiting, paresthesia, and decreased intraocular pressure
Topamax	Inhibits choroid plexus carbonic anhydrase, leading to decreased CSF secretion and the consequent control of intracranial pressure.	Vision disturbances, dizziness, drowsiness, confusion, speech and memory issues
11B HSD-1	Intracellular enzyme converts inactive cortisone to active cortisol, reduces CSF secretion.	Under study
GLP-1 agonist	Gut peptide with diuretic effect reducing NA+ re-absorption in renal proximal tubule, increasing NA+ water excretion contributing to possible reduction in CSF production.	Nausea

Literature Review

Title	Source
Optic disc edema, globe flattening, choroidal folds, and hyperopic shifts observed in astronauts after long-duration space flight (2011)	*Ophthalmology* DOI: 10.1016/j.ophtha.2011.06.021
Optic disc edema in an astronaut after repeat long-duration space flight (2013)	*Journal of Neuro-Ophthalmology* DOI: 10.1097/WNO.0b013e31829b41a6
Association of Structural Changes in the Brain and Retina After Long-Duration Spaceflight (2021)	*JAMA Ophthalmology* DOI: 10.1001/jamaophthalmol.2021.1400
Changes in the Optic Nerve Head and Choroid Over 1 Year of Spaceflight (2021)	*JAMA Ophthalmology* DOI: 10.1001/jamaophthalmol.2021.0931
Ocular Deformations in Spaceflight-Associated Neuro-Ocular Syndrome and Idiopathic Intracranial Hypertension (2023)	*Investigative Ophthalmology & Visual Science* DOI: 10.1167/iovs.64.3.32
MRI-based quantification of posterior ocular globe flattening during 60 days of strict 6° head-down tilt bed rest with and without daily centrifugation (2022)	*Journal of Applied Physiology* DOI: 0.1152/japplphysiol.00082.2022
Identification of Factors Associated With the Development of Optic Disc Edema During Spaceflight (2022)	*JAMA Ophthalmology* DOI: 10.1001/jamaophthalmol.2022.4396
Noninvasive indicators of intracranial pressure before, during, and after long-duration spaceflight (2022)	*Journal of Applied Physiology* DOI: 10.1152/japplphysiol.00625.2021
Changes in Optic Nerve Head and Retinal Morphology During Spaceflight and Acute Fluid Shift Reversal (2022)	*Journal of Applied Physiology* DOI: 10.1001/jamaophthalmol.2022.1946
Cerebrovascular Effects of Lower Body Negative Pressure at 3T MRI: Implications for Long-Duration Space Travel (2022)	*Journal of Magnetic Resonance Imaging* DOI: 10.1002/jmri.28102
Optic disc edema and chorioretinal folds develop during strict 6° head-down tilt bed rest with or without artificial gravity (2021)	*Physiological Reports* DOI: 10.14814/phy2.14977
Lower body negative pressure reduces jugular and portal vein volumes and counteracts the elevation of middle cerebral vein velocity during long-duration spaceflight (2021)	*Journal of Applied Physiology* DOI: 10.1152/japplphysiol.00231.2021
Intraocular pressure and choroidal thickness respond differently to lower body negative pressure during spaceflight (2021)	*Journal of Applied Physiology* DOI: 10.1152/japplphysiol.01040.2020
Association of Structural Changes in the Brain and Retina After Long-Duration Spaceflight (2021)	*JAMA Ophthalmology* DOI: 10.1001/jamaophthalmol.2021.1400
Mechanical countermeasures to headward fluid shifts (2021)	*Journal of Applied Physiology* DOI: 10.1152/japplphysiol.00863.2020
Effects of head-down tilt bed rest plus elevated CO2 on cognitive performance (2021)	*Journal of Applied Physiology* DOI: 10.1152/japplphysiol.00865.2020

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 3001] Selection and Recertification Crewmembers shall be medically and psychologically selected and annually recertified following the guidance in OCHMO-STD-100.1A, NASA Astronaut Medical Standards Selection and Annual Recertification.

[V1 3002] Pre-Mission Preventive Health Care Pre-mission preventive strategies shall be used to reduce in-mission and long-term health medical risks including, but not limited to: (see NASA-STD-3001 Volume 1 Rev C for full technical requirement).

[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 standard).

[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 standard).

[V1 3016] Post-Mission Health Care Post-mission health care shall be provided to minimize occurrence of deconditioning-related illness or injury, including but not limited to: (see NASA-STD-3001, Volume 1 Rev C for full standard).

[V1 3018] Post-Mission Long-Term Monitoring Crewmembers returning from spaceflight shall be monitored longitudinally for health, behavioral health, and well-being parameters in a standardized manner.

[V1 4020] In-Mission Nutrient Intake Programs shall provide each crewmember with 100% of their calculated nutrient and energy requirements, based on an individual's age, sex, body mass (kg), height (m), and an appropriate activity factor.

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

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Referenced Technical Requirements

NASA-STD-3001 Volume 1 Revision C

[V1 5002] Crewmember Training Beginning with the crewmember 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 spaceflight, psychological training, toxicology, medical equipment, 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.

[V1 6008] Crew Health Operations Concept Document The program(s) shall develop a crew health concept of operations document to define the medical and health care concepts during all phases of the spaceflight program.

[V1 6009] Medical and Crew Health Technical Requirements Document

NASA-STD-3001 Volume 2 Revision D

[V2 6001] Trend Analysis of Environmental and Suit Data The system shall provide environmental and suit monitoring data in formats compatible with performing temporal trend analyses.

[V2 6004] Nominal Vehicle/Habitat Carbon Dioxide The system shall limit the average one-hour CO2 partial pressure (ppCO2) in the habitable volume to no more than 3mmHg.

[V2 6022] Atmospheric Monitoring and Alerting Parameters The system shall alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO2, and ppCO2 are outside safe limits.

[V2 6107] Nominal Vehicle/Habitat Atmospheric Ventilation The system shall maintain a ventilation rate within the internal atmosphere that is sufficient to provide circulation that prevents CO2 and thermal pockets from forming, except during suited operations, toxic cabin events, or when the crew is not inhabiting the vehicle.

[V2 7100] Food Nutrient Composition The system shall provide a food system with a diet including the nutrient composition that is indicated in the Dietary Reference Intake (DRI) values as recommended by the National Institutes of Health, with the exception of those adjusted for spaceflight as noted in Table 7.1-2—Nutrient Guidelines for Spaceflight.

[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 7045] Medical Equipment Usability Medical equipment shall be usable by non-physician crewmembers in the event that a physician crewmember is not present or is the one who requires medical treatment.

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