ORIGINAL RESEARCH PAPER | Volume - 13 | Issue - 12 | December - 2024 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

DECOMPRESSION SICKNESS IN ASTRONAUTS: CHALLENGES, MITIGATION STRATEGIES, AND THE FUTURE OF AI IN EARLY DETECTION

Cardiovascular

Prof Dr Radhakrishnan Pradeep Kumar MS MCh CTVS AIIMS, Post-doctoral Fellow CTVS (SCTIMST) Fellow In ECMO (TSS, ISCU), FACC, FIACS, CPDH IISc, Global MBA, Fellow GAPIO, Vice Chairman IC Stem Cell Research Cardiac Surgery AMTZ, Chief Translational Research Cardiac Surgery Arkivis, Chief Cardiac Surgical Simulation One learning, Program Coordinator TAH And MCS, Hon Distinguished Fellow GAPIO, Mentor World Innovation Hub, Prof YANS Medical Institute Trivandrum, Hon Visiting Professor CTVS THI & TMRI

Prof Sanal Kumar V B Tech, M Tech, PhD Aerospace Engineering Amity University, India

ABSTRACT

As human space exploration advances, the risk of decompression sickness (DCS) poses significant challenges for astronaut health, especially during prolonged missions to the Moon and Mars. DCS arises from rapid pressure changes that cause nitrogen or inert gas bubbles to form in bodily tissues, leading to symptoms that can severely impair physical and cognitive function. The unique environments of the Moon and Mars exacerbate these risks due to prolonged exposure to low pressures, partial gravity, and extended extravehicular activities (EVAs). This paper synthesizes recent research into DCS risk factors specific to lunar and Martian missions and examines current and emerging mitigation strategies. Key findings reveal that tailored pre-breathing protocols, exercise during decompression, and optimized spacesuit pressurization are crucial for managing DCS in these settings. Additionally, AI-enabled predictive models are increasingly leveraged to assess personalized risk, simulate EVA conditions, and adapt decompression profiles in real-time. These models are instrumental in refining decompression strategies, integrating real-time physiological monitoring, and enabling dynamic suit adjustments. As artificial intelligence technology evolves, these systems will play an essential role in ensuring astronaut safety and mission success for deep-space exploration initiatives. This review highlights the latest advancements in decompression research, mitigation techniques, and the transformative potential of AI in managing DCS for the next generation of space missions.

KEYWORDS

INTRODUCTION

Decompression sickness (DCS), or "the bends," is a potentially severe condition that occurs from sudden pressure changes, causing nitrogen or other inert gas bubbles to form in body tissues. Though common among divers, decompression sickness also affects astronauts transitioning between pressurized environments, particularly during extravehicular activities (EVAs). With increased interest in Moon and Mars missions, understanding, mitigating, and detecting DCS in space is crucial. New AI technologies offer promise for predictive modelling and early detection, enhancing astronaut safety.

Unique DCS Risks in Martian and Lunar Missions

Exploration missions to Mars and the Moon present unique decompression challenges due to their distinct atmospheric and gravitational differences:

1. **Lunar Missions:** Lunar missions involve less gravity (1/6th of Earth's), but decompression risk remains significant during EVAs. Unlike the International Space Station (ISS), lunar missions require astronauts to operate at low pressures while wearing advanced spacesuits. Additionally, the Moon's lack of atmosphere and its surface dust compound decompression risks, as well as add respiratory and cardiovascular challenges (3).
2. **Martian Missions:** Mars presents new challenges, including prolonged exposure to partial gravity (1/3rd of Earth's). Decompression protocols for Mars will need to account for longer surface stays, varying activity levels, and extended EVAs. Mars missions also involve significant duration (approximately 6-9 months of travel each way), increasing DCS risks due to long periods in microgravity and subsequent re-adaptation to partial gravity (1).
3. **Extended Exposure to Low Pressures:** Due to mission requirements, both lunar and Martian missions expose astronauts to unique decompression profiles. The low-pressure suits for EVAs are designed for mobility, but they contribute to DCS risks by maintaining minimal ambient pressure. To address these risks, NASA has adopted exploration-specific atmospheres, which involve mixed gases and controlled decompression (4).

Mitigation Strategies for Decompression Sickness in Space

1. **Pre-Breathing Protocols:** Effective oxygen pre-breathing routines flush nitrogen from the blood, mitigating DCS risk. Lunar and Mars missions will likely use adapted pre-breathing profiles, possibly with light exercise, to optimize nitrogen expulsion (2).
2. **Suit Pressurization Adjustments:** Advances in suit design, incorporating flexible materials, allow for higher operating pressures without reducing astronaut mobility. This reduces the pressure gradient astronauts experience during EVAs, lowering DCS risk (5).
3. **Exercise During Pre-Breathing:** Studies show that light exercise during oxygen pre-breathing is effective at removing nitrogen. Lunar and Martian pre-EVA protocols might incorporate this approach, allowing astronauts to adapt to extended decompression (2).
4. **Algorithm-Driven Decompression Models:** Data-driven models are designed to assess astronaut-specific risks, integrating individual metabolic profiles with EVA conditions (4). These models adapt pressure levels dynamically, adjusting decompression profiles in real-time.

AI in Early Detection and Prevention of DCS

AI and machine learning are increasingly applied in astronaut healthcare for early DCS detection and risk management:

1. **Predictive Models for Personalized Risk Assessment:** AI algorithms assess DCS risk based on individual astronaut profiles, enabling tailored decompression protocols for each mission. This approach has shown promise in generating reliable, real-time EVA adjustments, reducing the possibility of DCS (1).
2. **Real-Time Physiological Monitoring:** AI-driven systems analyse data from wearables to detect changes in oxygen levels, heart rate, and blood pressure, providing early warning signs of DCS. These tools have been tested in microgravity environments to ensure accuracy and reliability (Ray et al., 2024).
3. **Advanced Decompression Algorithms:** New algorithms monitor pressure levels within the suit and vehicle, adjusting decompression rates based on real-time physiological and environmental data. These AI-enhanced algorithms have proven effective in adapting decompression in response to varied EVA scenarios (4).
4. **Simulation of EVA Scenarios:** AI models simulate various EVA conditions, helping researchers understand how environmental factors like duration and oxygen levels influence DCS risks. This knowledge is essential for developing safe operational protocols for Mars and Moon explorations (5).
5. **Long-Term Risk Prediction for Mars Missions:** With extended missions to Mars, AI models provide risk analysis based on long-term exposure and cumulative stress data, offering insights on

 PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

how repeated exposure to partial gravity and space conditions impact astronaut health (1).

Future Directions: AI and Decompression Sickness Prevention in Space Exploration

Emerging trends in AI applications, wearable tech, and spacesuit designs promise to enhance DCS prevention strategies:

- **Wearable Biometric Devices:** Integrating AI with biometric monitoring in spacesuits enables real-time DCS detection, reducing risks during EVAs and improving astronaut health on extended missions (Ray et al., 2024).
- **Automated Pre-Breathing Protocols:** AI models may autonomously regulate pre-breathing routines, enabling astronauts to skip lengthy sessions without compromising safety (2).
- **AI-Based Suit Adjustments:** "Smart" suits with integrated AI could self-adjust pressure based on real-time data, significantly lowering DCS risks and providing dynamic pressure control during EVAs (5).
- **Enhanced Data-Driven Research:** AI-enabled data analysis helps generate comprehensive DCS risk profiles based on cumulative EVA and mission data. This research supports safer EVA training and improves response protocols (4).

CONCLUSION

As human space exploration advances, addressing DCS becomes critical, especially for missions to Mars and the Moon. Through AI-enhanced prediction, monitoring, and responsive protocols, the risks associated with decompression can be effectively managed, ensuring astronaut safety on long-duration space journeys. AI's role in real-time DCS prediction and prevention offers exciting opportunities to expand human presence in space, making missions to Mars, the Moon, and beyond safer and more viable.

REFERENCES AND SUGGESTED FURTHER READING

1. Anderson, A., Fenbert, J., Easter, B., et al. (2024). "Quantifying Risk to Improve Medical System Design for Long Duration Artemis Missions: A Demonstration of NASA's IMPACT Trade space Analysis Tool." Presented at the 75th International Astronautical Congress.NASA Citation
2. Easter, B., et al. (2024). "Quantifying Medical Risk on a Long Duration Lunar Mission: A Demonstration of NASA's IMPACT Trade space Analysis Tool." NASA Full Text PDF
3. Ray, K., Deutsch, L., Garbino, A., et al. (2024). "Medical Outcomes from NASA's Exploration Atmospheres Study." Aerospace Medicine and Human Performance, 2024.EBSCOhost Access
4. Norcross, J., Walton, M. (2024). "Moon to Mars (M2M): Exploration Atmosphere." Trilateral Safety and Mission Assurance Conference.NASA Citation
5. SDS Risk, et al. (2024). "Managing Fatigue in Aviation: Preparing for Lunar Artemis Missions." Aerospace Medicine and Human Performance, Vol. 95, Issue 8. Ingenta Connect