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Corneal thermal burn injuries during long-duration spaceflight: mechanisms, evaluation, and management

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Embarking on long-duration spaceflights with limited resources and absence of immediate medical facilities necessitates careful consideration of potential health hazards in the unforgiving confines of space. Among the extensive possible risks inherent in space exploration, ocular injuries [1–3], particularly corneal thermal burns, stand out as significant focal points of concern. The Lifetime Surveillance of Astronaut Health database highlights numerous ocular injuries in the history of the U.S. space program, prompting concerns about potential vision-threatening injuries on the International Space Station (ISS) [4]. Reports of ocular, orbital, and cranial trauma during various ISS missions exist, but as of now, none have yet been secondary to a corneal thermal burn [5]. Recognizing the critical importance of understanding and efficiently addressing these injuries in space, this paper explores the unique circumstances that make corneal thermal burns a critical health concern for the Artemis Program and Martian missions. As the scope and duration of space exploration expands, especially in the context of commercialization, proactive approaches towards developing comprehensive protocols must addressed. This paper aims to discuss onboard diagnostic tools and potential modalities for treating thermal burns of the cornea during spaceflight with the current medications available on the ISS.

RISK FACTORS FOR CORNEAL THERMAL BURNS DURING SPACEFLIGHT

Examining the equipment used on the ISS reveals potential hazards and exposures to corneal thermal burns. Tools like the space oven for meal preparation highlight sources of heat the crewmembers interact with daily during their missions. The Zero G Kitchen Space Oven utilizes electrical heating elements to heat food to a nominal temperature of 177 degrees Celsius (350 degrees Fahrenheit) [6]. Although there is a cooling rack, and the space oven is thoroughly tested before integration into the ISS, technical malfunctions or exposure to hot food particles may induce a corneal burn. Moreover, the limited and confined nature of the spacecraft amplifies the risk of thermal burns, as the proximity of equipment and limited spatial freedom heightens the likelihood of accidental exposure to sources of heat. Crewmembers are also notably susceptible to radiant energy burns (aka flash burns) from direct or reflective UV light from the sun [7].

During a Apollo-Soyuz test project in 1975, propellant and combustion products (e.g., hydrazine, nitrogen oxide, nitrogen tetroxide) were inadvertently admitted into the cabin during re-entry [8]. In a hypothetical scenario with similar conditions aboard the ISS, the propellants could combine with other reagents to create an exothermic reaction and a potential burn risk to crewmembers [4]. Scientific experiments with flames or exothermic chemical reactions may put crewmembers at increased risk of obtaining corneal thermal burns as well. Terrestrially, gravity draws colder, denser air to the base of flames, thereby displacing hotter, lighter air upward. In a microgravity environment, flames do not exhibit upward flow and thus produce more unpredictable behaviours for combustion [9]. Flames in microgravity also may survive in less oxygen environments and burn for longer periods of time, thus increasing risk of thermal burns if an uncontrolled fire were to ignite [10].

DIAGNOSTIC AND MEDICAL MANAGEMENT

For crewed missions without a medical doctor, a designated medical officer is appointed who undergoes 40 h of paramedic-level training. This comprehensive training includes skills such as administering injections, suturing wounds, and implementing eye-washing protocols [11]. In the event of a corneal thermal burn injury, management should be initiated immediately with copious irrigation. A Space Eye-Wash apparatus is available aboard the ISS, complete with a saline solution for continuous irrigation. The device aids in removing potential foreign bodies and chemical exposures [12]. Topical anaesthetic (tetracaine (0.5%, 15 mL) is also available [13]. Following the eye-wash, the medical officer can complete the ocular examination including topical fluorescein staining of the cornea [14]. The crew also has access to remote health guidance from the terrestrial based flight surgeon and other subject matter experts on the ground at NASA's Johnson Space Center. Remote imaging including ocular photography, an onboard portable ocular ultrasound, and an optical coherence tomography (Heidelberg Spectralis OCT2) are available on ISS [15].

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The blink reflex typically prompts the eye to close when exposed to a stimulus taking longer than 0.1 s to travel to the eye [16]. Consequently, terrestrial thermal burns often impact the eyelid more than the conjunctiva or cornea. Mild eyelid burns can be irrigated with sterile isotonic saline solution, followed by the application of an ophthalmic antimicrobial ointment [17]. Fortunately, the risks for thermal burn in space impacting the conjunctiva or cornea is low and most mild cases resolve without significant complications [18]. Treatments available on the ISS include oral anti-inflammatory and analgesic treatments (Acetaminophen (Tylenol) 325 mg, Aspirin 325 mg, Ibuprofen (Motrin) 400 mg, Ketorolac (Toradol) 30 mg/mL (2 mL)); topical cycloplegic mydriatics (e.g., cyclopentolate (Cyclogyl, 2%, 15 mL) and tropicamide (Mydriacyl, 1%, 15 mL)); and topical ophthalmic antibiotics (Erythromycin ointment (0.5%); Moxifloxacin (Vigamox, 0.5%); Tobramycin and Dexamethasone (Tobradex), 0.3%; 0.1%) [13]. Cool saline compresses and adequate lubrication with artificial tears (Refresh Plus, 0.5%); Hypromellose (Nature's Tears, 0.4%); Mineral Oil and White Petrolatum (Refresh PM, 42.5%; 57.3%, 3.5 gm) can also be given as comfort measures.

In contrast to ISS missions, where evacuation to Earth is possible with a Crew Return Vehicle, lunar sorties, lunar outposts, Near-Earth missions, and a Mars mission do not provide evacuation options for an urgent return trip to Earth [19]. Additionally, the communication latencies, with up to 20 min for the signal to travel to and from Mars, will add complexity to medical decision-making processes [20]. Given the rapid advancements in machine learning, the integration of artificial intelligence (AI) into telemedicine may prove beneficial for determining optimal management steps, particularly in cases of corneal thermal burns where communication delays impede immediate intervention during medical emergencies [21]. Large language models specifically trained for space medical emergencies can potentially provide a suitable response in the absence of a doctor [22–24].

CONCLUSION

Although the risk for corneal thermal burn during spaceflight is low, awareness of the risks and prevention (e.g., safety goggles) may mitigate the need for potentially mission threatening interventions. Onboard ocular imaging technology supported by remote guidance on the Earth can manage most minor (e.g., corneal abrasion) or mild (eyelid thermal exposure) injuries. More severe injuries pose a greater risk in austere and distant environments (e.g., the moon or Mars) and AI enabled autonomous or semi-autonomous telemedicine may be useful countermeasures especially given the potential communication signal delay created by long distance space exploration. Testing these risk protocols in advance including virtual reality and computerized simulation may be warranted to reduce the risk for future long duration space travel.

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AUTHOR CONTRIBUTIONS

AS was responsible for the initial write up of the manuscript as well as the preliminary literature review for ocular injuries during spaceflight and terrestrial management of such injuries. AS reviewed the medications available on the International Space Station (ISS) and accordingly determined appropriate protocols for spaceflight treatment. JO was responsible for development of the research idea and approval of the outline before the manuscript outline was created. JO reviewed the first rough draft for quality control before extending to the other authors. EW provided additional expert advice on current ophthalmology practices as well as preliminary edits before extending to other authors. AGL oversaw the project and provided extensive initial edits, which highlighted artificial intelligence and emergent evacuation. All authors contributed beneficial insights and edits to ensure the success of the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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