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Review Article

Space Travel's Toll on Teeth: The Microgravity Perspective

Richa Wadhawan[1], Laishram Memory Devi [2], Ritesh Gupta[3], Abhimanyu Kumar[4], Abhijeet Kumar[5], Yashvardhan Shrivastava[6], Satyendra Singh Gurjar[7]

[1] Professor , Oral Medicine, Diagnosis & Radiology, PDM Dental College & Research Institute, Bahadurgarh, Haryana, India
[2] Private Practitioner, Delux Dental Care, Thoubal, Manipur
[3] Dental Surgeon, Three Star Eye And Dental Hospital, Birgunj, Nepal
[4] Dental Surgeon, Agastya Health And Dental Care, East Champaran, Bihar
[5] Private Practitioner, Bhuddha Dental Hospital, Patna, Bihar
[6]Dental Surgeon, Neelkanth Oral And Dental Clinic, Lalitpur, Uttar Pradesh
[7]Dental Surgeon, Maa Gayatri Dental Clinic,Sailana, Ratlam, Madhya Pradesh

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ABSTRACT

Space presents unique challenges to astronaut health, including in the oro-facial region, due to microgravity and radiation exposure. These conditions affect saliva production, microbial balance, and oral hygiene, increasing the risk of dental issues like caries, periodontal diseases, and discomfort. A comprehensive dental care approach is essential for astronauts' well-being during prolonged missions. This review paper explores space's impact on oral health, addressing challenges faced by astronauts, current dental practices in space, and strategies for maintaining oral health during prolonged missions. It emphasizes the importance of understanding microgravity's effects on physiology in advancing space exploration and also examines orthodontic tooth movement in reduced gravity environments and discusses potential challenges and solutions for dental health in space.

Humans have long dreamed of exploring space, which begins about 100 km above Earth's atmosphere. Space exploration, a reality since the late 20th century, has made routine journeys to new realms possible.[1] However; space travel induces significant physical and physiological changes due to microgravity, altered radiation, atmospheric pressure changes, temperature fluctuations, and density variations. These factors cause fluid redistribution and musculoskeletal alterations, necessitating adaptations in astronauts' vestibular and sensorimotor systems.[2]Additionally, astronauts face psychological effects, changes in microbial flora, and immunological alterations. The oral

* Corresponding author:
Richa Wadhawan, Professor,Oral Medicine, Diagnosis & Radiology, PDM Dental College & Resarch Institute, Bahadurgarh,Haryana, IndiaEmail: wadhawanricha1@gmail.com

and maxillofacial region is also impacted, leading to dental issues such as caries, periodontal diseases, fractures, pain, sensory abnormalities, and oral cancer. Addressing these challenges is crucial, prompting scientists to develop strategies for effective adaptation. Therefore, managing oral health is essential for astronauts' overall well-being during and after missions. Aeronautical dentistry, an emerging field, focuses on dental care in space.[3] This paper examines how space travel affects the oro-facial region and explores methods to mitigate these effects. While dental emergencies are rare during short missions, they pose significant risks during extended ones, as demonstrated by historical accounts like the 1972 Apollo-17 mission, which had an incidence rate of 0.01% per 100 days.[4] In 1977, Brown et al. estimated a 0.92% risk of an in-flight dental event affecting crew productivity.[5]The Integrated Medical Model identifies several dental conditions, such as cavities, abscesses, pulpal exposure, tooth avulsion, and the need for replacing dental crowns and fillings could be potential reasons for evacuating astronauts from the International Space Station. Dentistry in aerospace has advanced alongside aviation and space exploration.[6] In 1957, the U.S. Air Force established guidelines for dental care in space medicine.[7]

By 1960, an astronautical dental training program was in place to address space-specific challenges.[8] Major William Frome initiated initiatives for oral health among astronauts in 1966, while Colonel Johan Young pioneered zero-gravity dentistry in 1980.[9] Discussions on strategies to maintain dental health during prolonged missions were ongoing by 2000.[10] In 2006, Dr. Leon Dychter proposed the formation of the "International Association of Aerospace Dentistry." [11]

Discussion: Microgravity fosters dental plaque, tartar, and gingival inflammation, challenging oral hygiene. Elevated oral bacteria and delayed wound healing are observed, impacting dental health during prolonged missions. Bone demineralization at a rate of 1-2% per month in weightlessness increases dental issues and fracture risks on Mars missions, making the inclusion of a dentist and lab physician crucial. Barodontalgia, primarily caused by pulp diseases, can arise from new or recurrent caries, pulpitis post-restorative treatment, intratreatment endodontic symptoms, periodontal abscesses, and dental or periodontal cysts. Holowatyj RE concluded that pulpal hyperaemia is a key cause of barodontalgia. Using a zinc oxide eugenol (ZOE) base can prevent barodontalgia in cases of reversible pulpitis. For individuals exposed to significant pressure changes, avoiding procedures like pulp capping is advisable; instead, endodontic treatment may be indicated.[12] Calder and Ramsey introduced the term "odontecrexis" to describe tooth fractures caused by barometric pressure changes in high-altitude environments. These fractures occurred in teeth with poor-quality restorations, unrestored teeth, and those with or without caries due to gas expansion beneath restorations. Causes included fractures in porcelain-fused-to-metal restorations and pressure changes in the microtubules of dental cements, leading to crown dislodgement. DK Patel et al. found that teeth with mesiocclusodistal restorations were particularly susceptible to fractures.[13] Advances in space medicine reveal parallels with aging physiology, affecting multiple systems and necessitating alternative treatments like transcranial magnetic stimulation (TMS) for conditions such as dysphagia and burning mouth syndrome.[14] Space travel elevates bacterial activity due to confined conditions, increasing rates of periodontitis and caries. Spaceflight induces immune challenges, with reactivation of dormant herpes viruses due to microgravity, stress, and radiation. Alterations in white blood cells, reduced T cell effectiveness, and changes in cytokine secretion are observed. Salivary gland gene expression undergoes significant changes influenced by various factors, including functional activity and neurohormonal stimulation.[15] Research by Maija Mednieks and Aditi Khatri highlights altered expression of secretory proteins associated with beta-adrenergic hormone regulation via the cyclic AMP pathway.[16]Microgravity-induced fluid redistribution reduces saliva flow, causing xerostomia, while increased bone resorption elevates salivary calcium salt saturation, raising calculi formation risk. Environmental and dietary factors also worsen the situation. Prolonged missions heighten cancer risk and induce muscle wasting. Pre-breathing oxygen prevents decompression sickness during spacewalks, but radiation exposure on the International Space Station surpasses Earth's levels, elevating cancer risk. Interplanetary travel exacerbates this risk due to the absence of Earth's protective magnetosphere.[17] Microgravity reduces drug effectiveness, and barometric pressure changes may cause dental injuries. Osteoblast activity decreases, leading to monthly bone density loss of 1-2%. Traumatic injuries during space exploration raise the risk of jaw and dental injuries.[18] Disrupted cortisol and melatonin regulation may lead to temporomandibular joint discomfort. Persistent stress triggers bruxism and raises infection risks, while safety protocols target mortality rates below 3%. Decreased medication effectiveness leads to crew dissatisfaction, and altered drug absorption affects treatment outcomes. Barometric pressure changes, coupled with poor dental care, lead to dental issues like fractures or barodontalgia.[19]

Weightlessness increases fracture and muscle weakness risks due to reduced bone density. Pharmacokinetic research reveals changes in drug absorption, impacting treatment effectiveness. Barodontalgia uncovers underlying dental issues, while microgravity disrupts circadian rhythms, affecting the temporomandibular joint and bone mineral mass. Temporomandibular joint pain, linked to disrupted cortisol and melatonin regulation, may arise from stress hormone activity. Persistent stress and mental health conditions induce bruxism, potentially causing temporomandibular disorders and dental damage.[20] Microgravity-induced stress and sleep disturbances may also lead to temporomandibular disorders, causing psychological distress. Chronic stress and mental health challenges can exacerbate bruxism, potentially leading to dental damage.[21] In microgravity, a compromised immune system heightens infection risks during space missions. Pre-flight quarantines, established post-Apollo, have decreased infectious disease prevalence, yet minor infections like boils, styes, and periodontal issues persist on later missions.[22]In space exploration, traumatic injuries are a major concern, including both penetrating and blunt trauma which can cause severe harm. Maintaining oral health is crucial due to the challenges of dental emergencies and the increased risk of jaw and dental injuries caused by changes in bone density in microgravity conditions. The compromised immune system in microgravity amplifies the risks of infections, despite pre-flight quarantines to mitigate infectious disease prevalence. Minor infections such as boils and periodontal infections are still concerns.[23] To address these challenges, astronauts receive education on healthy diets and are encouraged to maintain scrupulous oral hygiene practices. Regular checkups are conducted, and the National Aeronautics and Space Administration have stringent criteria for selecting, retaining, and evaluating crew members' oral health.

Comprehensive clinical protocols involve annual oral examinations, with astronauts classified into three groups based on their oral health status. Overall, emphasizing prevention and maintaining oral health are vital for the success of space missions.[24]

Astronaut class	Description
Class I	Good oral health; no need for dental treatment or re-evaluation within 12 months
Class II	Some oral conditions present, but no imminent dental emergency expected within 12 months if left untreated
Class III	Oral conditions present, immediate dental treatment required to prevent a dental emergency within 12 months.

In space exploration, traumatic injuries are a major concern, including both penetrating and blunt trauma which can cause severe harm. Recent advancements in bandages and dressings, including tissue sealant dressings similar to fibrin-based adhesives, effectively control haemorrhage and reduce blood loss. Grounding of a patient is required when there is interference with the flight capabilities of the aircrew members. This can be caused by intake of medications, which causes side effects like headache, nausea and dizziness.[25] Due to the intra oral pressure, the blood clot which is formed after the surgical procedure in patient's mouth can come out and it can lead to intra oral bleeding. So, here, flight restriction is needed until the symptoms subside. Ensuring safety for both patient and clinician is paramount in microgravity. Maintaining surgical environment sterility and preventing wound contamination are critical due to weightless, non-sterile particles in the cabin. A reliable restraint system is essential in this unique setting. Sponges and suction effectively prevent cabin contamination from bleeding, except in cases of arterial bleeding, which pose a more complex challenge.[26]

Orthodontic Tooth Movement in a Microgravity Environment: Implications for Space Travel Microgravity in space disrupts physiological processes due to the absence of Earth's gravitational force, resulting in muscle atrophy, decreased bone density, fluid redistribution, and cardiovascular changes. Concerns arise regarding the functionality of orthodontic treatment in space, necessitating collaborative efforts among orthodontists, space medicine specialists, and bioengineers to devise innovative strategies. Orthodontic tooth movement relies on alveolar bone remodeling, which is influenced by forces' magnitude, direction, periodontal ligament health, and bone metabolism. Discussions on microgravity's health impacts have emerged with space travel, prompting studies on astronauts' head and neck regions.[27] Microgravity induces bone density reduction, known as spaceflight osteopenia, by decreasing bone formation and increasing resorption, leading to overall bone loss. These changes directly impact orthodontic procedures by potentially compromising tooth stability and movement. The Periodontal Ligament, crucial for orthodontic adjustments, relies on mechanical stimulation for its function. Microgravity disrupts cellular responses in the Periodontal Ligament, affecting its ability to support orthodontic forces and hindering tooth movement.[28] Orthodontic treatment in microgravity requires modifications for force control due to the absence of gravitational force. Concerns about bone remodeling efficiency may prolong treatment and complicate outcomes. Maintaining anchorage becomes crucial, as microgravity-induced bone loss can compromise stability, necessitating alternative strategies for effective treatment.[29] Research utilizing ground-based analogs, such as the hind limb unloading model in rodents, has provided insights into the effects of microgravity on bone and periodontal tissues. Studies have demonstrated that reduced mechanical loading results in decreased bone density and changes in Periodontal Ligament structure, similar to conditions observed in space. While direct studies on orthodontic tooth movement in actual spaceflight conditions are limited, experiments involving rodents in space missions have indicated significant alterations in bone and periodontal health, highlighting potential challenges for human orthodontics in space. To address the challenge of maintaining consistent forces in microgravity, potential solutions and adaptations may include redesigning orthodontic devices, with self-adjusting braces offering a possible solution.[30] Pharmacological agents such as bisphosphonates could counteract bone loss, while growth factors may promote bone formation.[31] Exercise and mechanical stimulation are essential for mitigating bone loss in microgravity.[32] Tailored protocols for astronauts undergoing orthodontic treatment can safeguard bone health and enhance tooth movement efficiency. Preventive dental care is critical during long-duration space missions, with regular check-ups facilitated through telemedicine and a rigorous oral hygiene routine to prevent dental complications. Emergency preparedness is vital due to challenges in providing dental care in space. Training astronauts in basic dental procedures and equipping spacecraft with necessary tools and materials ensure prompt management of orthodontic emergencies.[33]

Future Research Directions and Prospects: The evolution of aerospace dentistry depends on technological breakthroughs and comprehending space's influence on oral health. Prominent advancements encompass 3D printing for personalized dental prostheses, nanotechnology for radiation-resistant dental materials, and tele-dentistry leveraging Artificial Intelligence and wearable devices for continuous astronaut monitoring. Furthermore, investigating personalized medicine and integrating artificial gravity holds significant promise. Long-term research on microgravity's effects on orthodontic tooth movement is imperative, necessitating extended space missions to monitor changes and evaluate proposed solutions' effectiveness.[34]

Conclusion Dentists must screen flight crew members thoroughly, impose flight restrictions if needed, and inform them about postoperative flight consequences. Understanding oral and maxillofacial health effects in space missions is crucial for addressing microgravity-related complications as human exploration extends to Mars. This awareness has boosted demand for dental care among crew members, leading to aviation dentistry's establishment. Orthodontic tooth movement in microgravity poses significant challenges but also drives research and innovation.

Recognizing how reduced gravity affects bone and periodontal health is essential for effective orthodontic treatment during prolonged space missions. Enhanced orthodontic devices, pharmacological interventions, and preventive care can mitigate microgravity effects on astronauts' oral health. Persistent research and interdisciplinary collaboration are vital for advancing human space exploration.

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