Dermatologic manifestations in spaceflight: a review

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Abstract

With manned missions to Mars on the horizon, understanding and preparing for the medical conditions these astronauts might face becomes vital. According to the literature, the most commonly reported medical events in space are dermatological in nature. Dermatologic conditions rarely threaten an astronaut's life or the mission. However, manifestations and management of dermatologic events become an important consideration in anticipation of spaceflights to Mars and beyond. Given the limited number of articles written about dermatological conditions in this specific population, this review summarizes current knowledge related to dermatology in space. Overall, common dermatologic conditions found during spaceflight include viral reactivations, contact dermatitis or eczematous patches, and skin infections. Diagnosis and treatment can be difficult given the lack of resources in space as well as the hazards and side effects of certain treatments. In this review article we aim to summarize common skin changes induced by spaceflight, describe previously reported skin conditions including current treatment options, explore the risk of skin cancer in this unique population, and address the challenge of remote diagnosis.

Keywords: spaceflight, astronaut, immune system, contact dermatitis, skin cancer

Introduction

Over the last few decades humans have shown the ability to survive short- and long-term missions in the unique environment of space [1]. With the mission of landing a man on Mars as the new frontier, the task of providing medical care to an astronaut on the International Space Station (ISS) or shuttle becomes vital. In space, the most commonly reported medical event is dermatologic in nature, with an estimated incidence of 1.12 skin rashes per flight year compared to 0.044 cases per year on Earth [2]. In one study, 46% of 46 long-duration ISS crew members reported notable events, 40% of which were rashes [2].

Most dermatologic complaints in space have not been of a serious nature; some are easy to explain, such as the mild contact dermatitis from biosensor electrolyte paste experienced by the commander of Apollo 12 [3]. However, other dermatologic complaints are more difficult to explain, such as descriptions of dry, itchy, and thinning skin, increased sensitivity, and/or delayed wound healing [3]. Most experts agree that although dermatologic complaints are the most commonly reported medical event, they are the least likely of medical conditions experienced in space to seriously affect the completion of the mission and crewmembers' health [4, 5]. However, in anticipation of spaceflights to Mars and beyond, manifestations and management of dermatologic events become an important consideration. The purpose of this article is to review the prevalence and common manifestations of skin conditions in space, dermatologic treatments, and the risk of skin cancer in this population.

General skin changes in spaceflight

I. Collagen

One physiologic change during spaceflight is an increase in dermal collagen, up to 143% of normal, found following a 6-month mission [6, 7]. The effects

of this change are not, however, posited to have clinical ramifications. These changes, including the space-induced thinning and loss of elasticity, were found to be reversible after the astronauts' return to Earth [7]. Additional studies of skin changes noted during spaceflight are needed to further quantify and elicit possible clinical correlations.

II. Epidermal thinning

It is known that space flight exposes the skin to microgravity and cosmic radiation [3]. One study, using multiphoton tomography, demonstrated that astronauts after long-term space flights experience both thinning and loss of elasticity [3, 8]. The molting time of the cells from the stratum basale toward the stratum corneum has also been shown to be increased [8]. At the end of a 6-month mission, the epidermis was shown to be reduced to 30 micrometers compared to normal epidermis thickness, which ranges from 27-150 micrometers [6, 9, 10]. This thickness may be even further reduced following a trip to Mars [6].

Another study recently performed on the ISS took measurements of the inner forearm skin before, during, and after a long-term mission [3]. Each astronaut treated one forearm with a protective cream and the other untreated forearm served as the control. The treated forearm had fewer changes compared to the non-treated arm, which showed thinned stratum corneum, impaired barrier function, decreased hydration, and loss of dermal elasticity [3, 8]. This epidermal thinning is thought to expose the lower layers of the skin to low-wavelength ultraviolet light and radiation, possibly increasing the risk of skin cancer [6].

III. Microbiota

Shifts in the microbiota of the astronauts' skin has also been documented. Before the advent of 16S rRNA gene amplicon sequencing, Soviet scientists found differences after both short and long flights; however, early American flights (i.e. Apollo) did not find composition changes in the skin's bacteria [10]. Sugita et al. found that lipophilic skin fungi predominated before, during, and after spaceflight, but they observed that a specific or uncommon microorganism (such as the ascomycetous yeast *Cyberlindnera jadinii*) might be able to proliferate in a closed environment like that onboard the ISS [11]. Additional studies are needed to further qualify the changes of the skin's microbiota during spaceflight and to aid in preventing infections related to these changes.

Dermatologic conditions related to spaceflight

I. Atopic dermatitis

The environment in space, low humidity combined with extreme cold, puts astronauts with pre-existing atopic dermatitis at increased risk for acute flares during space flight [7]. In addition, immunological dysregulation as described previously can influence host response to this chronic pruritic inflammatory disease [4]. Standard treatment options include minimizing exacerbating factors, ample moisturization, topical or systemic corticosteroids, and antihistamines, some of which might not be conducive for space flight. For example, military pilots are limited in their treatment options as many oral medications, such as sedative antihistamines and systemic corticosteroids, are not permitted; topical hydration serves as the main alternative [7].

II. Contact dermatitis

Contact dermatitis has commonly been reported in space. For instance, during the Apollo 12 mission, the commander developed a skin reaction to a biosensor electrolyte paste [3]. According to the NASA history records, irritants causing contact dermatitis include micropore tape, fiberglass, beta cloth, ECG chest wall electrode patches, and the deerskin lining of a communication carrier [13,14]. Other articles have reported flight gloves, face masks, and headphones as inciting agents in aircraft pilots [7,15]. Consequences of contact dermatitis can be severe. For example, a military pilot was restricted from flying fighter aircrafts owing to allergic reaction to his oxygen face mask not controlled by preventative barrier creams. In anticipation of contact dermatitis, all Apollo crewman following the Apollo 12 mission episode of contact dermatitis were trained with materials identical to those used in flight and were specifically tested for reaction to all materials of allergic potential; thus, any observed skin reaction could be addressed on Earth prior to space flight [13].

III. Dry skin

One common dermatologic condition in space is that of dry skin [4]. Risk factors include advanced age, dry climate, such as that experienced in space onboard the ISS, and preexisting skin conditions. A study comparing photographs of skin before and after spaceflight showed aging-like skin changes — coarsening of the skin surface and epidermal thinning. These findings are likely related to decreased epidermal cell turnover and serve to elucidate the mechanism of xerosis in astronauts during spaceflight [6]. As mentioned previously, these changes in epidermal thickness are reversible after return to Earth [3, 6]. The treatment for this condition is moisturization.

IV. Infections in space

A. Contributing factors

i. Colonization and contamination

Studies examining the colonization of the ISS found skin-associated genera on board, including *Staphylococcus, Micrococcus, Bacillus, Streptococcus,* and some potentially pathogenic fungi [11]. The Russian Mir has also been studied for colonization, with isolates from various organisms including *Escherichia coli*, *Serratia marcescens*, a presumed *Legionella* species, spirochetes, and dust mites [16]. Aside from the contamination present onboard the shuttles or ISS, there is also an increased risk of direct transmission from person to person owing to the confined spaces [6]. For example, colonization and subsequent transfer of *S. aureus* between crew members has been commonly reported during spaceflight [17]. Additionally, even after spaceflight, *S. aureus* and beta-hemolytic streptococcus have been reported on astronauts' skin [17]. These studies show that the cause of rashes on space missions could very likely be infectious, but other etiologies have been noted and should not be excluded.

ii. Hygiene factors contributing to infectious risk

Hygiene factors that could contribute to the risk of infections or other rashes in space include no-rinse shampoos and soaps that are nor fully rinsed after cleansing [2]. Additional methods of cleansing while onboard include wet wipes, which was claimed to be the cause of a hypersensitivity eruption in one individual [18]. This same study found that the rate of using a medication to treat a rash was five times higher in their small cohort compared to that reported in submariners, who live in a closed environment and have a limited supply of freshwater for hygiene [18]. This report suggests that factors other than simply the constraints of hygiene in space are at play in the infectious rashes astronauts experience.

iii. Immune system dysregulation

Immune system dysregulation has been shown through studies onboard the ISS [19]. It is postulated that the causes of this dysregulation include physiological and psychological stressors, microgravity, and radiation [2]. These stressors can include isolation, confinement, anxiety, sleep deprivation, noise, and physical exertion [19]. Examples of immune system dysregulation include altered cytokine production, increased immunoglobulin levels, diminished natural killer cell, monocyte, and granulocyte function, inhibited leukocyte proliferation following activation, dysregulated T-cell intracellular signaling, and altered peripheral leukocyte distribution [2, 4]. Astronauts also have an increase in urinary excretion of stress hormones, such as cortisol and catecholamines, suggesting that stressors experienced in short and long duration flights contribute to this immune system dysregulation [19].

iv. Virulence, antibiotic resistance, and growth

Microgravity has been reported to induce changes in microorganisms including virulence, antibiotic resistance, and growth. The data is varied on microgravity's effects on bacterial virulence with some studies reporting increased [20, 21] and others finding reduced virulence [22].

Similarly, microbial antibiotic resistance in space is unclear as increased [23], decreased [24], and unchanged [25] resistance has been demonstrated. In one study, Urbaniak et al. discovered numerous genes conferring resistance to 28 antimicrobial agents. At the time of this study no methicillin resistant strains of *S. aureus* were identified [26]. With such discrepancies, there remains debate on resistance patterns to antibiotics in space. Additionally, the mechanism for altered virulence and antibiotic resistance is also still unclear [27].

Within the microgravity environment of the ISS, increased bacterial growth has been demonstrated [28, 29]. The cause is likely related to low-shear-stress and low-turbulence of this microgravity, an analogous environment to sites of bacterial growth in the human body [29]. There is a need for more studies on the changes in virulence patterns, antibiotic resistance, and growth of microbes onboard the ISS to be able to identify and accurately treat infections during spaceflight.

B. Infectious etiologies

Astronauts may be more prone to infections for various reasons including immune system dysregulation, hygiene constraints, enhanced microbial flora virulence, and contamination of the ISS from the shedding of astronaut's skin as previously described [2, 6]. Common infections include cellulitis, dermatophytosis, and herpes zoster reactivation. Most of the notable events on board the ISS in one study were prolonged rashes, followed by infectious diseases, atypical allergies, and cold sores [2].

C. Acne vulgaris

Acne vulgaris is not uncommon in space. In the military, severe nodulocystic acne can be a cause of rejection from service as these lesions can interfere with flying by affecting the seals of masks or respirators or straps of helmets. These nodules and cysts can also cause discomfort when sitting if they are located on the back [6].

Treatment varies depending on the type of acne vulgaris, but usually includes daily washes, topical and/or oral antibiotics, and topical retinoids. However, oral medications such as minocycline for acne vulgaris is discouraged in this patient population owing to an increased incidence of vertigo. Oral isotretinoin can cause decreased night vision and has been associated with corneal opacities, musculoskeletal symptoms, xerosis, and inflammatory bowel disease [6]. Avoidance of these medications is necessary to prevent adverse events that can affect the safety of the flight and crew.

D. Cellulitis

Cellulitis is a superficial skin infection that clinically appears as an erythematous, warm, and tender patch, generally in the setting of a prior trauma to that area. Cellulitis is commonly associated with the pathogens *Staphylococcus* and *Streptococcus*, both of which are skin-associated genera and have been found to colonize the ISS [11]. Oral antibiotics are used to treat cellulitis; however, additional studies are needed to provide information on antibiotic resistance of the microbes commonly implicated during spaceflight.

E. Dermatophytosis

Dermatophytosis is a fungal infection that occurs in the setting of moist environments and can occur during spaceflight. On Earth, treatment is with topical antifungal creams, such as butenafine, clotrimazole, or terbinafine. In space, the use of gels and powders is restricted given their potential for inhalation and flammability [4, 6].

F. Herpes reactivation

The reactivation of the herpes virus is thought to be related to the immune system dysregulation in space, with most reactivations occurring early in six-month space flights [2]. This theory is supported by one study which found that in the three astronauts who had no increases in their urinary cortisol or catecholamines there was no viral reactivation [30]. Other studies have shown a Th1 to Th2 cytokine shift in astronauts during both short and long duration flights, with increases in 10 plasma cytokines (IL-1α, IL-6, IL-8, IFNγ, IL-4, IL-10, IL-12, IL-13, eotaxin, and IP-10) in herpes virus-shedders verses non-shedders who had increases in only IL-4 and IP-10 [31, 32]. In viral shedders, IL-4 (Th2 cytokine) was increased 21-fold when measured on the astronauts' first day back on Earth, whereas IFNγ (Th1 cytokine) was only elevated 2-fold [31]. These results indicate that a shift to a Th2 response in spaceflight was elevated in astronauts with a latent virus reactivation [31].

An occurrence of 0.3 events per flight year was recorded in one study on the rate of herpes zoster reactivation in space flights [2]. The shedding of herpes viruses, such as cytomegalovirus, Epstein-Barr virus, and varicella zoster virus, has been seen in both short- and long-term missions to space. However, long duration flights result in more shedding that persists up to 30 days after return to Earth [19]. Based on this data, vaccination of

crewmembers prior to flight with varicella zoster virus vaccine is recommended [19].

V. Psoriasis

Psoriasis exacerbations have been noted in both military and space flight missions [4, 6]. Worsening psoriasis with excessive flying and repeated skin trauma has been reported in military pilots; with an analogous working environment, astronauts face a similar risk of psoriatic exacerbations [6]. Psoriasis may interfere with use of life support equipment and can thus prohibit a person from flying, such as when the Aerospace Medical Association Task Force on Space Travel prohibited persons with "severe skin diseases," such as psoriasis, skin tumors, or chronic pruritis from flight excursions [34].

Standard treatment includes minimizing stress, application of moisturizers, topical calcineurin inhibitors, and immunosuppressive agents. Unfortunately, these treatment options are limited in the field of aerospace. For example, concerns regarding neurotoxicity exclude the use of topical calcineurin inhibitors in military pilots [6]. Similarly, many oral medications, including the immunosuppressive agents methotrexate and sulfasalazine, are not allowed. Treatment is thus limited to topical emollients and occasionally topical steroids. Despite limited options, a case of inverse and plaque psoriasis in a military flight surgeon was successfully controlled with topical medications alone [34]. Additionally, minimizing stress becomes a complication when considering the inherent stressors of spaceflight: sleep deprivation, isolation from family, lack of privacy, physical stress, micro-gravity, launch, and reentry [35]. Studies have confirmed the physiological stress response in astronauts — salivary cortisol levels measured before and during space flight were found to be higher than those measured post-flight [30], and astronauts during launch and reentry were found to have elevated urinary cortisol and interleukin-6 [36].

VI. Skin cancer

Given the skin changes in space and increased exposure to cosmic radiation, it is theorized that astronauts on longer space missions will have an increased incidence of skin cancer. Current space missions occur in low Earth orbit, where Earth's magnetic field provides some protection against the radiation exposures of space [37]. In future spaceflights, for example to Mars, the risks of space radiation may increase as humans travel past the protection of the Earth's magnetosphere [37]. The National Council on Radiation Protection and Measurements has issued reports regarding the acceptable level of radiation for low Earth orbit; however, the council has not defined the level for sending manned missions to deep space [37, 38]. In 2008, the National Research Council of expert authors stated that the limiting factor for predicting the radiation risk associated with human space exploration was the lack of knowledge regarding the effects of space radiation [37, 39]. One radiation risk that the National Aeronautics and Space Administration has identified is carcinogenesis [37].

Due to the skin's superficial location and ability to absorb radiation particles, the skin's doses of solar particles can be up to 5–10-times higher than those experienced by internal organs [37]. Currently, astronauts on long-duration ISS missions have received more than 70 mSv of radiation [40]. Owing to the various confounding factors, it remains to be determined whether higher doses of radiation in space missions outside of lower Earth orbit will increase the risk of cancer for astronauts [37]. No studies have shown conclusively that exposures to certain doses or dose rates in outer space will result in an increased cancer mortality compared to the general population, but this data is not specific to dermatologic malignancies [41-43].

One longitudinal study of 312 United States astronauts found that there were 33 diagnoses of basal cell carcinoma and localized squamous cell carcinoma. This was a statistically-significant three-fold increase in prevalence in these cancers over a comparison study. However, the study noted that astronauts spend a significant amount of time outdoors for their training and recreation. Therefore, the contribution of time spent in space on the risk of developing skin cancer is difficult to determine [3]. Other confounding factors to understanding how to interpret this data include the relatively low doses and dose rates of radiation during spaceflight in low Earth orbit, the wide range of time intervals between

spaceflight and diagnosis of cancer, and the overall small sample size of those who have flown in space [37].

VII. Urticaria

Urticaria is a skin rash resulting in pruritic, erythematous plaques typically triggered by an allergic reaction. In some cases, the eruption is accompanied by angioedema. The diagnosis of idiopathic urticaria puts military pilot fitness into question and a history of angioedema and anaphylaxis render someone permanently unfit to fly [6].

Urticaria may also arise in response to decompression sickness [6]. This phenomenon occurs when nitrogen trapped in tissues is released upon sudden exposure to low atmospheric pressure [6, 44]. Decompression sickness can affect astronauts during an extravehicular activity, thereby compromising the astronaut's ability to complete their assigned task [45]. Typical symptoms include musculoskeletal pain and cutaneous manifestations such as mottling of the skin, though cutaneous changes only occur in 10% of cases [46]. Treatment of decompression sickness includes high partial-pressure oxygen, with definitive treatment of hyperbaric oxygen [46, 47]. Hyperbaric oxygen therapy increases oxygen to ischemic tissues, decreases edema in the tissues, and eliminates the dissolved nitrogen in tissues [46]. Prevention of decompression sickness via inhalation of oxygen, or partial denitrogenation, has decreased the number of reported decompression sickness cases after spaceflight and extravehicular activities [45].

Resources for diagnosis: Diagnosis of dermatologic conditions can be challenging during spaceflight. The advent of telecommunication, and the growth of teledermatology, can help to overcome this challenge to some extent. However, onboard surgery or biopsies and staining of specimens is not currently feasible. In the future of space exploration, advances in teledermatopathology and teledermoscopy can provide additional information regarding skin lesions or skin eruptions to providers on Earth to ensure the safety of the crew members [48-50].

Conclusion

Dermatologic complaints are among the most commonly reported medical events during spaceflight. As such, being able to properly identify and treat these conditions is paramount to the safety of both the astronauts and the space mission, especially as missions become longer. This review article provides information on common manifestations of dermatologic conditions that occur during spaceflight, as well as current issues with treatment onboard the ISS. As the final frontier of space continues to be explored, including a mission to Mars, teledermatology as well as advances in formulations of medications will aid diagnosis and management of these common dermatological problems and assure comfort for future space missions.

References

1. Toback AC. Space Dermatology: a specialty in evolution. *Cutis* 1991;48:283-7. [PMID: 1743061].
2. Crucian B, Babiak-Vazquez A, Johnston S, et al. Incidence of clinical symptoms during long-duration orbital spaceflight. *Int J Gen Med*. 2016;9:383-391. [PMID: 27843335].
3. Burgdorf WHC, Hoenig LJ. Dermatology and the american experience in space. *JAMA Dermatology*. 2015;151(8):877. [PMID: 26267470].
4. Grover S. Skin in aviation and space environment. *Indian J Dermatol Venereol Leprol.* 2011;77:413-7. [PMID: 21727688].
5. Billica RD, Simmons SC, Mathes KL, et al. Perception of the medical risk of spaceflight. *Aviat Space Environ Med* 1996;67:467-73. [PMID: 8725475].
6. Arora S. Aerospace dermatology. *Indian J Dermatol*. 2017;62(1):79. [PMID: 28216729].
7. Seitzer U, Bodo M, Muller PK, et al. Microgravity and hypergravity effects on collagen biosynthesis of human dermal fibroblasts. *Cell Tissue Res*. 1995;282(3):513-7. [PMID: 8581945].
8. Tronnier H, Wiebusch M, Heinrich U. Change in skin physiological parameters in space: report on and results of the first study on man. *Skin Pharmacol Physiol*. 2008;21(5):283-292. [PMID: 18663342].
9. Dubey P. Dependence of absorption and scattering spectrum over melanin concentration. *IJESET*. 2016;8(4):2231-6604. ISSN: 2231-6604.
10. Yudovsky D, Pilon L. Rapid and accurate estimation of blood saturation, melanin content, and epidermis thickness from spectral diffuse reflectance. *Appl. Opt*. 2010;49(1):1707-1719. [PMID: 20357850].

11. Stabler RA, Rosado H, Doyle R, et al. Impact of the Mk VI SkinSuit on skin microbiota of terrestrial volunteers and an International Space Station-bound astronaut. *NPJ Microgravity*. 2017;3(1):23. [PMID: 28894789].
12. Sugita T, Makimura K, Cho O, et al. Comprehensive analysis of the skin fungal microbiota of astronauts during a half-year stay at the International Space Station. *Med Mycol*. 2016;54(3):232-9. [PMID: 26773135].
13. Hawkins WR, Zieglschmid JF. SP-368 Biomedical results of Apollo. section II, chapter 1: clinical aspects of crew health. http://history.nasa.gov/SP-368/s2ch1.htm. Accessed April 12, 2018.
14. Toback AC, Kohn SR. Manifesto of space medicine: the next dermatologic frontier. *J Am Acad Dermatol.* 1989;20:489-95. [PMID: 2645326].
15. Gan WH, Koh CH, Low R. Contact urticaria from an oxygen mask in a military pilot. *Aviat Sp Environ Med*. 2010;81(8):785-788. [PMID: 20681240].
16. Ott CM, Bruce RJ, Pierson DL. Microbial characterization of free floating condensate aboard the Mir space station. *Microb Ecol* 2004;47:133-6. [PMID: 14569419].
17. Taylor GR. Recovery of medically important microorganisms from Apollo astronauts. *Aerospace Med*. 1974; 45:824-828. [PMID: 4153037].
18. Wotring VE. Medication use by U.S. crewmembers on the International Space Station. *FASEB J*. 2015;29(11):4417-4423. [PMID: 26187345].
19. Mehta SK, Laudenslager ML, Stowe RP, et al. Latent virus reactivation in astronauts on the international space station. *NPJ Microgravity*. 2017;3(1):11. [PMID: 28649633].
20. Nickerson CA, Ott CM, Mister SJ, et al. Microgravity as a novel environmental signal affecting Salmonella enterica serovar Typhimurium virulence. *Infect Immun*. 2000; 68:3147–3152. [PMID: 10816456].
21. Rosenzweig JA, Abogunde O, Thomas K, et al. Spaceflight and modeled microgravity effects on microbila gorwth and virulence. *Appl Microbiol Biotechnol*. 2010;85:885-891. [PMID: 19847423].
22. Hammond TG, Stodieck L, Birdsall HH, et al. Effects of microgravity on the virulence of Listeria monocytogenes, Enterococcus faecalis, Candida albicans, and methicillin-resistant Staphylococcus aureus. *Astrobiology. 2013;*13:1081–1090. [PMID: 24283929].
23. Tixador R, Richoilley G, Gassett G, et al. Study of minimum inhibitory concentration of antibiotics on bacteria cultivated in vitro in space (Cytos 2 experiment). *Aviat Space Environ Med*. 1985;56:748–751. [PMID: 3899095].
24. Juergensymeyer MA, Juergensmeyer EA, Guikema JA. Long-term exposure to spaceflight conditions affects bacterial response to antibiotics. *Microgravity Sci Technol*. 1999;12:41-47. [PMID: 11543359].
25. Kacena MA, Todd P. Gentamicin: effect on *E. coli* in space. *Microgravity Sci Technol*. 1999;12:135–137. [PMID: 11868575].
26. Urbaniak C, Sielaff AC, Frey KG, et al. Detection of antimicrobial resistance genes associated with the International Space Station environmental surfaces. *Sci Rep*. 2018;8(1):1-13. [PMID: 29339831].
27. Klaus DM, Howard HN. Antibiotic efficacy and microbial virulence during space flight. *Trends Biotechnol*. 2006;24:131–136. [PMID: 16460819].
28. Klaus D, Simske S, Todd P, et al. Investigation of space flight effects on *Escherichia coli* and a proposed model of underlying physical mechanisms. *Microbiol*. 1997;143:449-455. [PMID: 9043122].
29. Nickerson CA, Ott CM, Wilson JW, et al. Microbial responses to microgravity and other low-shear environments. *Microbiol Mol Biol Rev*. 2004;68(2):345-361. [PMID: 15187188].
30. Mehta SK, Laudenslager ML, Stowe RP, et al. Multiple latent viruses reactivate in astronauts during space shuttle missions. *Brain Behav Immun*. 2014;41(1):210-217. [PMID: 24886968].
31. Mehta SK, Crucian BE, Stowe RP, et al. Reactivation of latent viruses is associated with increased plasma cytokines in astronauts. *Cytokine*. 2013;61(1):205-209. [PMID: 23107825].
32. Crucian BE, Stowe RP, Pierson DL, et al. Immune system dysregulation following short- versus long-duration spaceflight. *Aviat Space Environ Med*. 2008;79:835–43. [PMID: 18785351].
33. Aerospace Medical Association Task Force on Space Travel. Medical guidelines for space passengers. *Aviat Space Environ Med* 2001;72:948-50. [PMID: 11601561].
34. Hagen AD, Sulit DJ, Sulit AK. Cutaneous psoriasis in a military flight surgeon. *Aviat Space Environ Med.* 2006; 77(2):140-144. [PMID: 16491582].
35. Mehta SK, Cohrs RJ, Forghani B, et al. Stress-induced subclinical reactivation of varicella zoster virus in astronauts. *J Med Virol*. 2004;72:174-179. [PMID: 14635028].
36. Stein TP, Schluter MD. Excretion of IL-6 by astronauts during spaceflight. *Am J Physiol*. 1994;266:448-452. [PMID: 8166266].
37. Chancellor JC, Scott GBI, Sutton JP. Space radiation: the number one risk to astronaut health beyond low earth orbit. *Life : Open Access Journal*. 2014;4(3):491-510. [PMID: 25370382].
38. National Council on Radiation Protection and Measurements (NCRP). Information needed to make radiation protection recommendations for space missions beyond low-Earth orbit. *NCRP*; Bethesda MD, USA: 2006.
39. Committee on the Evaluation of Radiation Shielding for Space Exploration. Managing space radiation risk in the new era of space exploration. National Academies Press; Washington, DC, USA: 2008.
40. Shavers MR, Zapp N, Barber RE, et al. Implementation of alara radiation protection on the ISS through polyethylene shielding augmentation of the service module crew quarters. *Adv Space Res*. 2004;34:1333–1337. [PMID: 15880921].
41. Hamm PB, Billica RD, Johnson GS, et al. Risk of cancer mortality among the longitudinal study of astronaut health (lsah) participants. *Aviat Space Environ*. 1998;69:142–144. [PMID: 9491253].
42. Peterson LE, Pepper LJ, Hamm PB, et al. Longitudinal study of astronaut health: mortality in the years 1959–1991. *Radiat Res*. 1993;133:257–264. [PMID: 8438068].
43. Behnken R, Barratt M, Walker S. Presentation to the institute of medicine-ethics principles and guidelines for health standards for long duration and exploration spaceflights. *National Aeronautics and Space Administration*; Washington, DC, USA: 2013.
44. Dunbar B, Strauss S, Conkin J. Preventing decompression sickness on spacewalks. *National Aeronautics and Space Administration*. Last edited: Feb 21, 2013. Accessed on April 12, 2018.
45. Conkin J. Preventing decompression sickness over three decades of extravehicular activity. *The NASA STI Program*. 2011. NASA/TP-2011-216147.
46. Pollock NW, Buteau D. Updates in decompression illness. *Emerg Med Clin North Am*. 2017;35(2):301-319. [PMID: 28411929].
47. Lee KJ, Sanou AZ. Decompression sickness in the F/A-18C after atypical cabin pressure fluctuations. *Aerosp Med Hum Perform*. 2018; 89(5):478-482. [PMID: 29673435].
48. Coates SJ, Kvedar J, Granstein RD. Teledermatology: From historical perspective to emerging techniques of the modern era: Part II: emerging technologies in teledermatology, limitations and

future directions. *J Am Acad Dermatol*. 2015;72:577-86. [PMID: 25773408].

49. Rajagopal R, Sood A, Arora S. Teledermatology in air force: our experience. *Med J Armed Forces India.* 2009;65:342-6. [PMID: 27408289].

50. Kaliyadan F, Ramsey ML. Teledermatology. StatPearls. Treasure Island, FL: StatPearls Publishing; 2018 Mar 28. Available from: https://www.ncbi.nlm.nih.gov/books/NBK459382/. Accessed on April 12, 2018.