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Space travel: A challenge from the point of view of ophthalmology

Viagem espacial: Um desafio sob o ponto de vista da oftalmologia

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ABSTRACT

At the end of the twentieth century, with the emergence of new technologies and new space programs, aerospace medicine gained prominence in the scientific community since studies related to changes in human physiology in space have become increasingly necessary for the maintenance of cosmonaut health. The eyes are considered one of the most sensitive structures in the body to vascular, structural and biochemical changes caused by microgravity and cosmic radiation. In this sense, this narrative review seeks to identify and explain the main morphological and functional changes that occur in the visual system as a result of space missions.

Keywords: *Aerospace Medicine; Eye manifestations; Cosmic radiation; Cataract; Papilledema*

RESUMO

No final do século vinte, com o surgimento de novas tecnologias e de novos programas espaciais, a medicina aeroespacial ganhou destaque no meio científico uma vez que os estudos relacionados às alterações da fisiologia humana no espaço tornaram-se cada vez mais necessário para a manutenção da saúde de cosmonautas. Os olhos são considerados uma das estruturas mais sensíveis do corpo às alterações vasculares, estruturais e bioquímicas provocadas pela microgravidade e radiação cósmica. Nesse sentido, essa revisão narrativa busca identificar e explicar as principais alterações morfológicas e funcionais que ocorrem no sistema visual em decorrência de missões espaciais.

Descritores: Medicina Aeroespacial; Manifestações oculares; Radiação cósmica; Catarata; Papiledema

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Introduction

The "Cold War" period was marked by the bipolar tension between the United States of America (USA) and the Union of Soviet Socialist Republics (USSR), which competed for political, technological and economic hegemony.[1,2] This period was also known for the development of the first missiles and space rockets, which gave birth to the "Space Age".[2]

John Franklin Kennedy, former U.S. president, announced the plan to take the first man to the Moon in 1961. At that time, knowledge on acceleration, air pressure and microgravity effects on the human body were still quite scarce.[3-5]

Space medicine started to conduct studies on the physical effects of suborbital spaceflights on the human body, such as those performed by the International Space Station, satellites and space missions that go beyond Earth's orbit — including human missions to the Moon and Mars.[5,4]

Eye health is assumingly one of the biggest challenges of human space exploration, since the eyes are partially protected by the eyelids, which are important barriers against aggressive agents like radiation.6 Moreover, Earth's ozone layer surrounds the entire planet and blocks UV radiation emitted by the sun and several celestial bodies in space.[6]

The human eye structure is closely linked to terrestrial radiation and atmospheric pressure.[7] Microgravity triggers blood redistribution to the upper body, which becomes congested due to increased blood hydrostatic pressure.[7] Cerebral venous congestion directly affects intraocular pressure and can damage the optic disc, such as papilledema and retinal hemorrhages.[7,8]

Thus, the aim of the present study was to review the effects of microgravity and eye exposure to space radiation on the human body.[8,9]

Methodology

The present study is a literature review about human adaptation to space and the ophthalmic changes caused by it. PubMed, LILACS, Scielo and Google Scholar databases were selected to cover the research. The keywords "space", "ophthalmology" and their respective Portuguese equivalents were entered into the databases. Articles addressing the following issues in section "abstract" were included in the present study: ocular changes caused by microgravity and space radiation; vascular changes in astronauts during space missions. Twenty articles were found, of which 8 were excluded for not meeting the inclusion criteria. Thus, 12 articles were selected, regardless of their language.

Results

Eye changes described in the present review resulted from microgravity and space radiation. (Table 1) The reviewed studies state that the ocular structure is very sensitive to the space environment; thus, optic disc edema, cotton wool spots, choroidal folds and cataracts are common ocular changes.

Changes in the circulatory system may also affect the visual system. Severe venous congestion leads to optic nerve damage, such as papilledema and periorbital edema. Optic nerve protrusion and posterior globe flattening — both detected through imaging examination — are also assumingly caused by human space exploration.

Furthermore, prolonged exposure to microgravity leads to increased intracranial pressure (ICP), whose main clinical symptoms include visual disturbances, nausea, projectile vomiting and headache. Yet, symptoms such as cancer susceptibility, degenerative and dystrophic changes are also described by astronauts. The phosphene phenomenon, which has also been mentioned by some of them, results from the effect of ionic particles on the retina. Finally, choroidal folds can arise as the result of papilledema.

Discussion

Since the first interplanetary travel and the development of new American spaceflight programs like Projects Gemini

Table 1
Analysis of studies indicating visual system changes caused by exposure to microgravity and radiation.

Authors	Study Site	Ophthalmology findings
Aleci 2020 [6]	Turin, Italy	Optic disc edema, retinal cotton wool spots, cataracts and phosphene phenomenon.
Kandarpa et al., 2019 [7]	Tamil Nadu, India	Cerebral venous congestion leading to optic nerve damage.
Lee et al., 2017[8]	Houston, United States	Papilledema, cotton wool spots.
Kramer et al., 2012 [9]	Houston, United States	Posterior globe flattening (27%), optic nerve protrusion (15%).
West 2000 [10]	California, United States	Cardiovascular diseases leading to periorbital edema.
Michael et al., 2015 [11]	Illinois, United States	Nausea, projectile vomiting and visual disturbances.
Takahashi et al., 2018 [15]	Gunma, Japan	Increased cancer risk and development of degenerative diseases, such as cataracts.
Kleiman et al., 2017 [16]	New York, United States	The visual system is the first to be affected by radiation.
Sannita et al., 2006 [19]	Rome, Italy	Phosphene phenomenon.
Zhang et al., 2018 [20]	Shanghai, China	Cataracts.
Ivanov et al., 2018 [22]	Tübingen, Germany	Increased cancer risk and dystrophic changes.

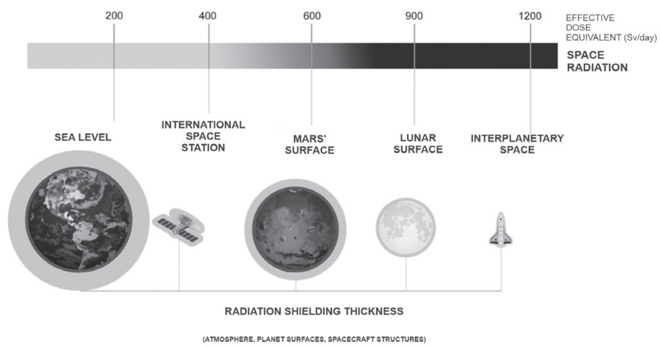

Figure 1: Space radiation exposure rate in different environments*

*Figure designed by Cunha CEX. (2020) by using Freepik.com resources (https://br.freepik.com/)
Different solar system environmental conditions whose radiation rate is inversely proportional to atmospheric/structural thickness, according to Sato et al.[18]

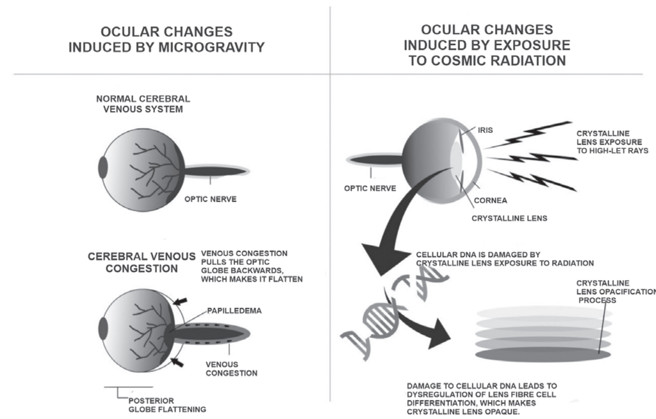

Figure 2: Main structural and physiological changes associated with microgravity and cosmic radiation*.

*Figure designed by Cunha CEX. (2020) by using Freepik.com resources (https://br.freepik.com/)

Pathophysiological mechanisms described by Aleci.(6)

and Apollo, health risks of space exposure have been proven dependent on space travel's time and distance,[7,10] as well as new physical changes.[10] The main changes observed by these programs included osteoporosis (bone density and calcium loss) nitrogen imbalance and decreased red cell mass, all resulting from the body's high metabolic rates during space missions.[10-12]

Earth's atmosphere is known as "Earth's protective shield", which surrounds the planet and protects it from the cosmic rays emitted by celestial bodies. Moreover, the terrestrial atmosphere exerts a constant and unidirectional force (gravity) on the bodies close to it.[6] Therefore, the human body becomes vulnerable to space radiation when it moves outside this "shield" .[6]

A study carried out with cosmonauts from the International Space Station evidenced that one third of the crew who returned to Earth had ocular symptoms resulting from increased ICP and cosmic radiation.[13]

These symptoms arise because the eye structure is very vulnerable to cosmic radiation: The skin — an important protective barrier — surrounding it can be eroded.[6] Cucinotta et al.[14] claim that the likelihood of astronauts developing radiation-induced cancer is closely linked to exposure time and astronauts' age group.[14,15]

The crystalline lens is a very radiosensitive structure; therefore, it can suffer opacification upon exposure to radiation levels lower than 0.5 Gy.[16] Radiation affects human body tissues through two main mechanisms: [6] direct cell injury (irreversible mutations leading to cell death) [6,17] and indirect cell injury (free radical formation leading to imbalance of nearby molecules).[17]

Moreover, space radiation exposure varies according to the atmosphere of planets or satellites.[6] (Figure 1) The lunar surface, for instance, has radiation levels higher than those of Mars, because the Moon has a small surrounding gas layer, whereas Mars' atmosphere is thicker than that of the Moon.[15,18]

There are two ocular phenomena resulting from eye exposure to radiation: phosphene and cataracts.[6] Phosphene derives from damage to the vitreous and crystalline humors; astronauts describe it as moving or fixed white spots that affect normal eyesight and show up while reading and driving.[6,19,20]

With respect to cataracts, the higher the radiation exposure rate, the greater the likelihood of developing it. [6] This disease is most prevalent in astronauts who participated in lunar or high-inclination missions, since it results from cosmic high-LET radiation [6,19] (Figure 2). Cataract is the opacification of the eye lens, whose function is to focus light rays onto the retina and help in the visual accommodation process.[20,21]

Cataracts' pathophysiology involves post-translational modifications of crystallin proteins induced by genetics or even direct damage to cellular DNA.[20] High-LET radiation causes DNA damage by inducing the formation of free radicals, such as reactive oxygen species.[6,22] Such damage results in dysregulation of lens fiber cell differentiation, which makes the lens opaque and consequently reduces visual acuity.[20,22]

Microgravity can also lead to structural changes in the visual system.[14] DNA fragmentation damages cell matrices, which triggers mutations in the cell nucleus. It can also induce cardiovascular and skeletal changes.[6,8]

Pathological changes in the eyes of astronauts after long-term space missions have been reported by the National Aeronautics and Space Administration's (NASA) department of Medicine.[8] Optic disc edema, globe flattening, choroidal folds, cotton wool spots and refractive errors are the most reported pathological findings by NASA. [8] (Figure 2) A study carried out with astronauts after long-term space missions showed that 60% of them presented decreased near and far visual acuity.[23]

Another study carried out by Kramer et al.[9] showed the effects of microgravity on vision through ophthalmic diagnostic imaging: 4 (15%) of twenty-seven astronauts presented optic nerve swelling and 7 (26%) of them presented posterior globe flattening.[10]

Microgravity reduces blood hydrostatic pressure and, consequently, heart pumping. [10] Therefore, blood is redistributed to the upper body, which leads to arterial swelling and jugular venous distension.[6-8,10] Astronauts commonly present periorbital edema and general facial edema.[10]

Microgravity can also impair cerebrospinal fluid (CSF) circulation by making fluid accumulate in the interstitial and/or intracellular compartments.[8,23] This condition induces increased intraocular and intracranial pressure, which leads to edema of the entire CSF.[23,24]

Papilledema stands out among the aforementioned findings because it is related to ICP and can be detected through funduscopic examination.[23] Papilledema is defined as swelling of the optic nerve, since its compression by the cerebral edema impairs ocular blood flow.[23])

On the other hand, choroidal folds are undulations of the retinal pigment epithelium, Bruch's membrane and inner choriocapillaris. Although they have several etiologies, they have been mostly associated with papilledema since their first description in the literature.[24]

Hypobaric hypoxia is another common eye disease induced by microgravity, due to the low partial pressure of oxygen (O_2) in space.[25] Decreased O_2 levels in the blood hinders tissue oxygenation and requires adaptive mechanisms to prevent hypoxia from affecting many human tissues.[26]

A study carried out by NASA with 250 crew members of the Space Shuttle program assessed individuals exposed to low O_2 levels 1-3 days after the end of their missions.[25] Gastric discomfort, appetite loss and headache were some of the study's findings. Yet, eye symptoms can also appear as a result of retinal hypoxia.[25,26]

Retinal hemorrhage is the first retinal manifestation of hypobaric hypoxia. However, vitreous hemorrhage, papilledema and retinal vein occlusion may also be indicative of it.[26]

Conclusions

Remarkable technological progress — such as the construction of better and safer aircraft — has been made since Sputnik's launch. Additionally, the harmful effects of spaceflight on the human body have been widely acknowledged, and it made it possible understanding how radiation and microgravity affect the optical system and clinical findings from space exploration.

Accordingly, it is important to care for astronauts' eye health not only by encouraging further studies on spaceflight, but also by developing technologies that protect and keep them safe, with the least possible health damages.

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