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REVIEW ARTICLE OPEN ACCESS

Space Nursing for the Future Management of Astronaut Health in other Planets: A Literature Review

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Abstract:

Introduction: The idea of exploring space excites more than one person, and not only astronauts but health professionals are also not indifferent to it because for a long time, human healthcare in space has been a priority directly involving the nursing profession; however, there is not much information available on this subject that it's becoming more relevant every day.

Objective: This study aims to explore, review, and analyze existing literature to identify the basic needs of astronauts, nursing roles, and the challenges they will face in the context of human space exploration.

Methods: A literature review was conducted with bibliographic evidence of documents annexed to the following databases: WoS, MEDLINE through PubMed, Scopus, SciELO, CINAHL-EBSCO and Google Scholar. Previously, a search strategy was designed with descriptors: "Astronauts," "Space Flight," and "Nursing in Care," using Boolean operators "OR" and "AND". The languages were English and Spanish, there were no restrictions on the type of document and date of publication.

Results: 23 documents were selected after applying the inclusion and exclusion criteria. The following results found in the present review have been categorized into 8 thematic areas: historical background, conceptual models and nursing theories applied to space, space environment, physiological changes in space flights, health problems and risks in space, nursing care in space and management of nursing care in space. Finally, future challenges of space nursing. Each of these categories is presented below.

Conclusion: Space Nursing has been constantly developing and its interventions will be required along with the advances in space exploration. It encourages innovation, implementation, building a knowledge base, and discovering new modalities of human healthcare to reach the frontiers of space.

Keywords: Space, Health, Space nursing, Spaceflight, Astronaut, Nursing care.

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1. INTRODUCTION

Since ancient times, humanity has had a great passion for the sky and the stars [1]. This fascination has been reflected in numerous literary and religious works and the diversity of creative manifestations arising from the human intellect [1, 2]. Thanks to scientific and technological advances, the mysteries of the universe are being revealed as novel discoveries [2]. An important milestone in this regard was on April 12, 1961, when Russian cosmonaut Yuri Gagarin became the first person to travel into space aboard the Vostok 1 spacecraft [3, 4]. Since then, spaceflight has experienced enormous technological advances in recent years.

This decade will usher in a new space age, with the emergence of commercial spaceflight and space tourism offered by companies such as SpaceX, Virgin Galactic and Blue Origin [3, 5]. At the same time, the Artemis program of the National Aeronautics and Space Administration (NASA) started the launch of the Space Launch System (SLS) rocket and the Orion crew capsule on August 29, 2022. This program aims to return humans to the lunar surface (Apollo 11) to establish a base station to serve as a training ground for future manned missions to Mars [5, 6]. Globally, many space agencies and programs are collaborating and contributing to the technological development of space exploration [2, 7].

However, as humanity's journey into space increases, challenges related to human health and crew safety also increase [8, 9]. Maintaining good health is essential to achieving successful space missions in the future. Each space mission requires unique medical capabilities, a specific composition of astronauts, and sound medical policies. Space science has sparked interest in many professions that contribute in an interdisciplinary way to finding solutions to human health problems [2]. Nursing has played an important role in the space program for many years, although none of its members have been selected as astronauts [1]. However, they have been part of the health team, ensuring medical care and attention before, during, and after space flights [9]. Furthermore, it is evident that future generations of nurses will be able to provide comprehensive medical care and consider the basic needs of human beings in space conditions.

Martha Rogers inspires and motivates us to embrace the holistic nature of wellness and the influence of the environment [10]. Their particular approach helped us recognize the influence of the space environment on the health and well-being of astronauts, as well as their ability to adapt to microgravity, radiation exposure, and psychological interactions. By integrating these theories into space nursing practice, it is possible to effectively address the needs of astronauts and ensure their well-being during space missions. The objective of the article is to carry out a bibliographic review to identify nursing care and the basic needs of human beings (astronauts) in the context of space exploration or space flights. The article seeks to explore and analyze the role of nursing in human health care in space before, during and after space flights. In addition, it aims to explain what nursing care in space environments would be like in the future and identify the challenges that will be encountered in the future of human space exploration. To develop the structure of this review, it has been divided into 8 categorical dimensions based on time and existing relevance proposed by Gómez *et al*. [9]: historical background, nursing theories applied to space, and spatial environment. Environment, physiological changes in space flights, health problems and risks in space, nursing care in space flights, management of nursing care in space and its future challenges.

2. MATERIALS AND METHODS

The methodology used in this study was a review of the literature, since it collects and integrates findings and perspectives from various previous investigations [11]. For this article, the following guiding question was initially posed: What are the nursing care and basic needs of human beings (astronauts) in the context of space exploration or space flights? Which made it possible to determine the unit of analysis during the documentary review process. The research was carried out between December 2022 and February 2023. The evaluation was based on the analysis of relevant international literature on the topic.

2.1. Search strategies

The bibliographic search was carried out through the following databases: Web of Science (WoS), MEDLINE through PubMed, Scopus, SciELO, CINAHL-EBSCO and Google Scholar. The languages considered were English and Spanish. Likewise, other research studies were incorporated to keep the bibliographic review updated and obtain new perspectives, approaches, or findings that can enrich or strengthen the study. There were no restrictions on article type and publication date. The search strategy was designed for each database using DeCS and MeSH descriptors, as well as Boolean operators ("AND" and "OR") [12]. Field labels with descriptor terms, (Table **1**).

2.2. Selection Criteria

Regarding the selection criteria of the articles, after the electronic search, they were previously exported to the Rayyan QCRI application (https://rayyan.qcri.org) for selection, classification and evaluation [13]. Initially, duplicate records that were not specifically related to the research topic were eliminated. Subsequently, the titles, summaries and full articles were read. This activity has allowed us to evaluate concordance and homogenization if the identified records were relevant to the topic and met the research objectives. They imposed no restrictions on article type or publication date, suggesting that a wide range of articles were demonstrated for inclusion. The selection process is highlighted in the flowchart [12], as shown in Fig. (**1**).

2.3. Ethical Aspects

Ethics committee approval was not sought for the study as this study involved a review of bibliographic databases.

Table 1. Database search strategy.

Main Category	N°	Keywords in Boolean Search Format	Search Mask
Astronaut	#1	(Astronaut* OR Cosmonaut OR Cosmonauts)	All fields
Spaceflight	#2	("Flight, Space" OR "Flights, Space" OR "Space Flights" OR "Spaceflight" OR Spaceflights OR "Space Travel" OR "Space Travels") TI= (Spaceflight OR Aerospace OR Microgravity) [1]	All fields Titles
Nursing Care	#3	("Nursing Care" OR Nursing)	All fields
-	#4	#1 AND #2	All fields
-	#5	#1 AND #2 AND #3	All fields
-	#6	#1 AND #3	All fields

Note: [1] Web of science.

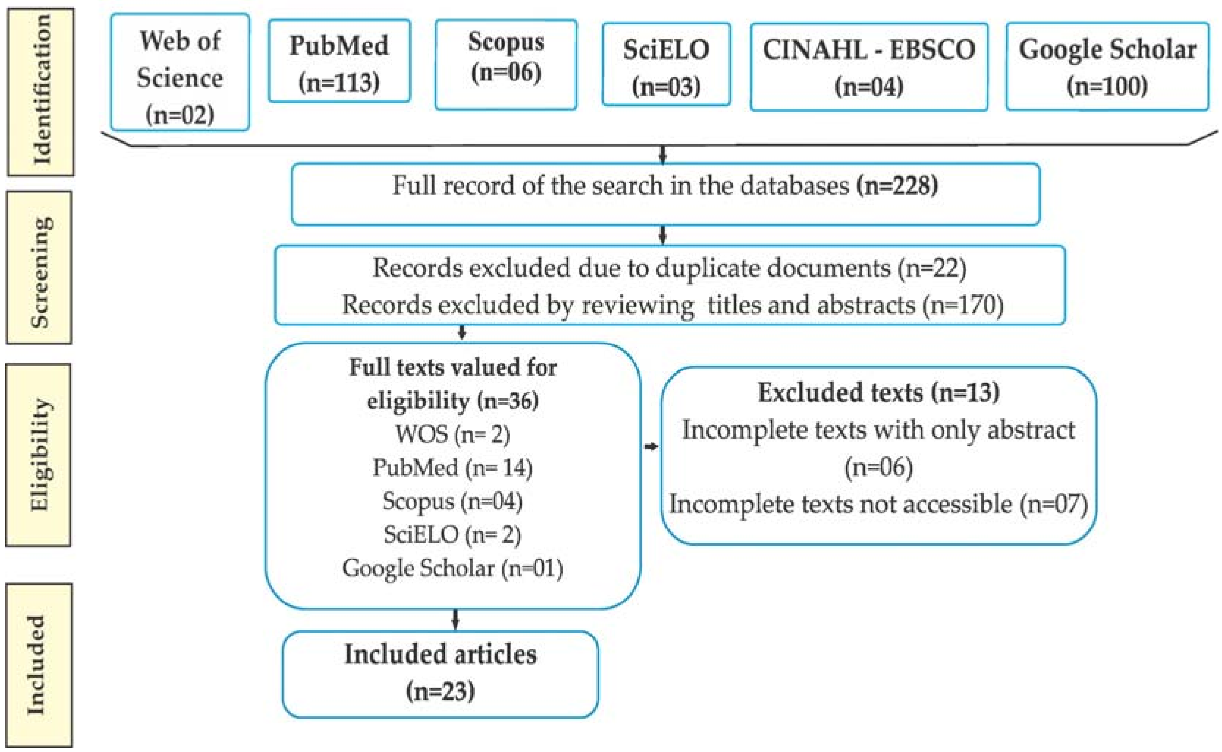

Fig. (1). Flowchart for selection of studies retrieved from databases.

2.4. Limitations

This review has methodological limitations due to the lack of information and the dispersion of the types of documents found on the topic, which has made it difficult to carry out an exhaustive systematic review, which is why the decision was made to carry out a literature review. Furthermore, another important limitation was the difficulty in accessing complete documents, which affected the depth of the analysis of the results obtained.

3. RESULTS

In total, 228 scientific documents were registered, the elimination of 22 duplicate documents continued, 170 that did not meet the objectives of this research, including 23 documents that met all the inclusion criteria; of which 13 were journal articles, 1 book, 2 original articles, 3 review articles, 1 bibliographic review, 1 editorial, 1 historical article and 1 article of personal experience.

Some of the characteristics of the 23 documents included are shown in Appendix A. On the other hand, taking advantage of the usefulness of its functions of the Rayyan QCRI Web Tool, it has continued to analyze the countries with the highest number of scientific publications related to space nursing. Being the United States (USA) the country that leads with the highest scientific production at 72%, followed by others such as Brazil and China with 6%. The rest of the nations, like Mexico show 3%, similar to Canada and Spain. In turn, Mexico and Brazil are located with a higher percentage in relation to the other Latin American countries, (Fig. 2).

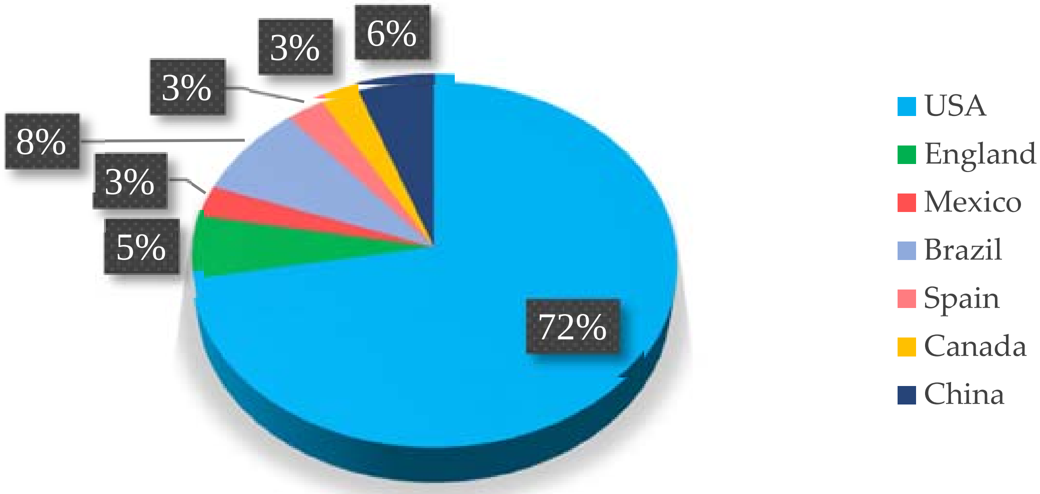

Fig. (2). Distribution of publications on space nursing by country.

The findings were grouped into eight large areas: 1) Historical background; 2) Conceptual models and nursing theories applied to space; 3) spatial environment; 4) Physiological changes in space flights; 5) Health problems and risks in space; 6) Nursing care in space; 7) Management of nursing care in space and 8) Future challenges of space nursing. Each of these categories is presented below.

3.1. Historical Background

The practice of caregiving has been an integral part of human history, evolving alongside the migration of humans to different environments. Florence Nightingale, a pioneer in the field, laid the theoretical foundation of care and helped establish nursing as a science [8, 14]. As human presence expands, including into space exploration, the importance of care practices becomes even more apparent [15, 16].

In the 1920s, a new era began with the inclusion of nurses as part of aircraft crews. On May 15, 1930, Ellen Church became the first nurse assistant and flight attendant [14]. After World War II ended in 1943, she continued her career as a captain in the Army Nurse Corps Air Evacuation Service. This marked the beginning of flight nursing, with the first graduates of the Evacuation School in Bowman Field, Kentucky [14, 17]. Since then, academic advancements have been made to equip nurses with new skills. Many of these skills were already part of the flight nurse section of the Aerospace Medical Association (AsMA), established in 1963. Others were assigned to support bio-astronomical operations in the U.S. Air Force Army [14, 18].

In 1959, Dee O'Hara became the first American nurse assigned to provide emergency medical care to astronauts and their families during the Project Mercury VII mission [1, 9, 15, 17, 19]. Before this assignment, she had worked at Patrick Air Force Base in Cape Canaveral, Florida. She was later recruited as a nurse to evaluate and monitor the health of astronauts in the mentioned project [15]. In 1958, a year before the creation of NASA by President Eisenhower, the institution announced the formation of the Space Nursing Program in 1962 [1].

Eight years later, Martha Rogers emphasized that the role of nurses extended beyond Earth and into extraterrestrial environments [8-10]. To put this idea into action, Linda Plush and Martha Rogers founded the Space Nursing Society (SNS) in 1991, during a private dinner held at the University of Alabama in Huntsville, near NASA's Marshall Space Flight Center. Since its inception, the SNS has grown from 10 nurses and 1 pharmacist to over 350 active members from countries such as the United States, Canada, various European countries, Greece, and Australia [14, 15]. The purpose of this organization was to create new opportunities for the specialty of space nursing and advocate for the preservation of human health beyond Earth's boundaries [1, 14].

3.2. Conceptual Models and Nursing Theories Applied to Space

Nursing, with a long history dating back to the Crimean War, has played a crucial role in creating healthcare environments that prioritize well-being [9,15,17]. Over the years, it has evolved to address different scenarios and has expanded its focus to more deeply understand the interactions between humans and their environment [8,17].

Importantly, Martha Rogers' theory has been widely recognized in the field of nursing and has contributed significantly to the spatial nursing approach [9,15,17].

Their particular approach highlights the interconnection between humans and their environment, recognizing the holistic nature of well-being [9,10,15,20]. Over time, nursing has evolved to address different scenarios and has expanded its focus to more deeply understand the interactions between humans and their environment [8,17].

Authors such as Gomez *et al*. [9] and Symanski [15] and others have contributed ideas and concepts to interpret, extrapolate and adapt to spatial environments. By incorporating these theories into space nursing practice, it is possible to effectively address the needs of astronauts and ensure their overall well-being during missions. The integration of multiple conceptual models and theories in nursing not only reflects the dynamic nature of the profession but also demonstrates its ability to adapt and thrive in novel and challenging environments [3,5].

- Martha Rogers: has made an important contribution with her unique approach and extensive research and debate. Their approach highlights the relevance of the connection between human beings and their environment, recognizing the integral nature of well-being [10]. According to this theory, nurses should focus on promoting harmony and balance between astronauts and their environment in space, taking into account the various factors that exist [21].
- Virginia Henderson: focuses on basic human needs and the role of nurses in helping people meet those needs. His theory can be applied to the care of astronauts in space by addressing their physiological and psychological needs. In the context of space, this theory suggests the need for nurses to support astronauts in maintaining their physical well-being, assisting them with nutrition, hygiene and mobility, and providing them with emotional support to cope with the challenges of living in a space, a confined and unique environment [9].
- Florence Nightingale: Known as the founder of modern nursing, she developed a theory that emphasized the importance of the environment in promoting healing and well-being. His theory can be applied to the care of astronauts in space by focusing on creating a favorable environment that promotes physical and psychological health [9, 17].
- Callista Roy: developed the Adaptation Model, which focuses on the individual's ability to adapt to changes in the environment. This theory can be applied to the care of astronauts in space, considering their adaptation to the microgravity environment and the challenges it poses to their physical and psychological well-being [15]. In addition, it suggests evaluating and promoting the adaptive responses of astronauts, providing interventions to support their adaptation, and evaluating the effectiveness of these interventions. This may include strategies to manage physical changes, and psychological stressors, and promote adaptation to the space environment [8, 9, 15, 17].
- Jean Watson: emphasizes the importance of the nurse-patient relationship. This theory can be applied to the care of astronauts in space by recognizing the need for compassionate and supportive care in a challenging and isolated environment. The theory also suggests that nurses should establish a caring and trusting relationship with astronauts, provide them with emotional support, and create a healing environment that promotes their well-being. This may involve activities such as active listening, therapeutic communication, and creating opportunities for meaningful connections [9, 15].
- Madeleine Leininger: on the diversity and universality of cultural care focuses on the importance of cultural competence in nursing care. While the cultural aspect may be less relevant in the context of space, Leininger's theory highlights the need to consider the unique needs and preferences of astronauts in the provision of care. This may include understanding your individual beliefs, values and preferences related to health and well-being [8, 15].
- Dorothea Orem: focuses on the ability of individuals to engage in self-care activities to maintain their health and well-being. In the context of space, it suggests that nurses should help astronauts develop and maintain their self-care capabilities in a unique and challenging environment. This may involve providing education and training on self-care techniques, assisting with the management of health conditions, and promoting independence in activities of daily living [4].

3.3. Space Environment

The space environment beyond 100 km above sea level presents multiple challenges for the human body, including acoustic noise and vibrations, extreme temperatures, ionizing radiation, microgravity, and relative geometry [1, 5]. These factors can have significant impacts on the health and well-being of astronauts during space exploration missions.

The ambient temperature in space can vary significantly depending on the location and exposure to sunlight. On the side of the spacecraft facing the sun, temperatures can reach up to 100 °C (212 °F), while in the dark shadow, temperatures can drop to as low as -55 to -100 °C (-67 to -148 °F). These extreme temperature variations pose challenges for astronauts and the equipment they use [1, 9]. To protect themselves from extreme temperatures, astronauts rely on the thermal control systems of their spacesuits and spacecraft [9]. These systems use insulation, heating elements, and cooling mechanisms to maintain a comfortable temperature range inside the spacesuit and spacecraft.

Electromagnetic and cosmic radiation from outer space pose a significant challenge for human space exploration. These radiations include Galactic radiation (coming from outside the solar system), solar radiation (high-energy protons from the sun), and particles trapped in the magnetosphere (Van Allen) [1, 4, 5, 9, 15]. These subatomic particles have high ionizing power and can penetrate living tissues, causing damage ranging from small burns to cancerous lesions in sensitive organs such as the bone marrow, lymph nodes, and testes [4, 15, 22].

The severity of the effects depends on the dose and duration of radiation exposure [5]. To protect astronauts from radiation, space craft, and spacesuits are equipped with shielding materials that can absorb or deflect a significant portion of the radiation. Additionally, astronauts are monitored for radiation exposure, and their missions are carefully planned to minimize their time in high-radiation environments [5, 22].

Microgravity, also known as zero gravity or weightlessness, is another important factor in the space environment [1, 15]. It occurs when the sum of forces on a body is zero or less than this value, causing the body to be in free fall away from the gravitational force exerted by a planet. This phenomenon is experienced by astronauts aboard the Space International Station (ISS), which orbits the Earth [8, 15, 22]. The absence of gravity in space has profound effects on the human body (see section on physiological changes) [5].

Relative geometry refers to the spatial orientation and positioning of objects and individuals in the space environment [5]. In the absence of gravity, the concept of “up” and “down” becomes relative, and astronauts must adapt to a new frame of reference. The lack of a clear sense of direction and orientation can cause disorientation and difficulties in spatial perception. Astronauts must rely on visual cues, instrumentation, and training to navigate and perform tasks in space [5, 23].

3.4. Physiological Changes in Spaceflight

For a long time, the human body has developed and evolved under the influence of Earth's gravity. However, when entering a microgravity environment, psychological and physiological changes associated with spaceflight are generated [17, 19]. For this, we describe more relevant aspects of each of them. The immediate effects begin with the loss of the acceleration vector after launch, especially with the alteration of fluid redistribution (2000 ml) from the lower extremities to the upper region of the body, causing symptoms such as facial plethora [1, 9, 22], nasal congestion, redness of the eyes [5, 19, 22], eyelid thickening, swelling of the neck [1, 3, 19] and face [1, 19].

This phenomenon generates a state of cardiovascular deconditioning due to the increase in pressure and volume in the filling of the heart chambers [5, 9, 17]. In prolonged spaceflights that exceed 6 months, some of the astronauts may present cardiac arrhythmias due to a state of dysfunctionality whose causes can be due to loss of minerals [1], ionic alterations, changes in cardiac conduction, and the presence of alternating T phenomena [15]. While at the level of the respiratory system, no major changes affecting human performance have been reported or the data are limited [1]. Despite this, there are slight modifications, such as reduced ventilation, tidal volume, and increased respiratory rate due to the decrease in the weight of the abdominal organs [9].

After the first weeks of arrival in space, space adaptation syndrome occurs and most astronauts have neuro-vestibular effects, a deficit in balance control [4, 9, 17, 22], incoordination, and motion sickness caused by alterations of fluids in the semicircular canals of the inner ear causing spatial disorientation, vertigo and illusions of posture, angular and linear movement (neurosensory conflicts) [9, 23]. In addition, symptoms of increased intracranial pressure (ICP), such as nausea, vomiting, headache, and lethargy due to fluid migration are included [4, 9]. In the sense organs, there is the disorganization of the gustatory, tactile, and visual sensory patterns [1]. The neuro-ophthalmic changes are produced by increased intraocular pressure (IOP) [4, 5, 9], distension of the optic nerve, and posterior flattening of the balloon precisely by retro-ocular edema, and which also generates difficulties in the phenomenon of accommodation [9, 19].

There are also musculoskeletal changes related to the pattern of physical activity and the protein nutritional balance they carry in space. The initial manifestation is characterized by decreased protein synthesis characterized by an important decrease of muscular mass and loss of muscle strength [4, 9, 22], which can subsequently lead to severe muscle atrophy (disuse atrophy) of the flexor muscles and with a predominance of the posterior or extensor muscles [4, 22, 23].

The integrity of the bone system has been compromised by the disappearance of compressive forces [23], lack of mechanical stimulation, and low illumination (which produces a decrease in the synthesis of vitamin D), generating the slow loss of calcium and other minerals; being the most affected the bones of the legs and spine [1, 4, 8, 19, 22]. In this regard, many of NASA's technical reports have indicated that there is an evident loss in bone mass density of approximately 20% [5] and 25% for prolonged periods, so the skeletal structural system becomes fragile and susceptible to the risk of fracture [1, 4, 8, 19, 22].

This release of calcium from the bones not only increases the risk of fractures [9], but it has also been observed that the rapid loss of these bone minerals is released into the bloodstream, and from there, it is excreted outside through the urine, increasing the possibility of precipitation and the frequency of suffering from renal lithiasis. In some cases, the risk of urinary tract infections can be added too [4, 9, 19, 24]. The level of the digestive system has been evidenced by decreased gastrointestinal transit (probably associated with the motion sickness of the first days), changes in the mucosal barrier and imbalance or dysfunction of the intestinal microbiota [1, 3, 9, 19].

Another biological interaction affected is immune dysregulation, which generally has a multifactorial origin; the best known occurs due to various situations of stress, mostly psychological and those induced by cosmic radiation that is capable of generating oxidative stress and damaging immune cells [9]. Promoting abnormal production of interleukin function and, depressed activation of granulocytes, lymphocytes, and alteration of immunoglobulins reducing their responsiveness to pathogens [1, 4, 21]. Consequently, it has been shown that these opportunistic germs (bacterial and viral) increase their capacity for multiplication [5, 23] and virulence by mutation under space conditions [4, 22].

Finally, space is an exceptional environment that also tests the limits of human psychology [5, 9], since living for prolonged periods in closed environments and working in small spaces drastically affect the psychological sphere; especially after the breakdown of the family womb and the complex interpersonal relationship they normally had on earth [14, 15, 25]. The feeling of deep isolation and stress due to the distance that exists between the Earth and the ISS [4, 24]. Both situations influence sleep patterns, which affects cognitive function that is reflected in decreased intellectual performance, memory, concentration and physical condition regardless of the astronaut's levels of preparation [19, 25].

3.5. Health Problems and Risks in Space

During space exploration, astronauts face unusual and even catastrophic threats [19]; we have been able to identify some of them that can become medical emergencies that compromise the lives and safety of travelers [9, 15]. These problems can go unnoticed within the ISS and during the performance of Extravehicular Activities (EVA) [26]. One way to predict these situations is by analyzing the probability of occurrence and it is classified as follows:

3.5.1. Mild

Space adaptation syndrome, Space Motion Sickness (SMS), vomiting, dizziness, gastrointestinal symptoms [23], severe malaise [1, 8, 23], headache [26], joint pains [15], tiredness, fatigue [1], uncomplicated urinary tract infection [4], upper respiratory tract infection [9], simple lacerations, muscle strains [26], sprains [21], anxiety and depression [8].

3.5.2. Moderate

Gas emboli in the heart and blood vessels by spacesuit decompression [15], cardiac arrhythmias [3, 15, 22], uncomplicated myocardial infarction, perforated duodenal ulcer, respiratory disorder syndrome, nephrolithiasis, diverticulitis, appendicitis, open chest wound, head injury, burns greater than 40% of the body [9, 15], fractures [15], space anemia [19], complicated urinary tract infection [4], hemorrhages with hemodynamic compromise, ionizing radiation [26] and III degree sprains [21, 27].

3.5.3. Severe

Explosive spacesuit decompression [15], micro-meteorite accidents, severe concussions [26], sepsis, shock, and complicated cardiac arrhythmias [9].

3.6. Nursing Care in Space

Nursing is one of the largest professions in the world with many benefits in health services due to its main foundation and application of the theoretical-scientific methodological process [28]. In the space field, it has been involved as part of a multidisciplinary field with a holistic approach based on human needs and responses where human beings can live and work [9, 25]. This section, it is based on the proposals made by Gómez *et al*. [9]. This proposal allows us to understand and address care in a structured and synchronized manner in clinical occupation programs in weightless environments. Likewise, the exhaustive analysis of nursing care paradigms is separated into specific stages (before, during, and after) since they allow for more specialized care adapted to the needs identified in previous years in astronauts in each phase of space flight [9]. This will ensure in the future that we provide the best possible care and minimize health risks to astronauts during their space missions, Table **2**:

3.6.1. Before Spaceflight

- Monitoring and evaluating anthropometric measurements and vital signs [4].
- Conducting regular health checks before, during, and after space travel [5].
- Creating an emergency plan for evacuating various injuries in orbit, the cabin, and the transporter [27, 29].
- Providing support through physical examinations and medical research tests prior to the mission [1, 14].
- Recognizing the value of cultural identity, traditions, and beliefs as a unifying element within the crew [9, 19].
- Offering education and promoting health for crew members [3, 4, 21].
- Providing first aid instructions and education [4].
- Supervising and managing the astronaut immunization program [1, 21].
- Developing a nursing intervention plan based on the 14 universal human needs [9].
- Verifying and testing the functionality of medical devices and sensors using the principles of crew human-machine interface [16, 22, 26, 30].

Table 2. This table shows all documents that address the basic needs of the human being.

No.	Basic Needs	References	%
1	Oxygen	[1, 5, 9, 21, 22, 24, 26, 27]	9%
2	Nutrition and hydration	[1, 4, 8, 9, 17, 22, 23, 26].	9%
3	Excretion	[5, 9, 22, 23, 24]	6%
4	Movement and position	[1, 4, 5, 8, 9, 15, 17, 19, 22, 23, 27]	13%
5	Sleep and rest	[5, 8, 9, 17, 21, 23]	7%
6	Dress	[9, 15, 21, 22, 26]	6%
7	Thermoregulation	[4, 9]	2%
8	Hygiene	[9, 21, 22, 24]	5%

No.	Basic Needs	References	%
9	Dangers	[3, 4, 5, 9, 15, 17, 21, 22, 24, 26]	12%
10	Communication	[3, 4, 9, 15, 17, 19, 22, 23, 24, 26]	12%
11	Values and beliefs	[8, 9, 19, 21, 26]	6%
12	Work	[5, 9, 19, 26]	5%
13	Recreational activities	[9, 17, 21]	4%
14	Learning	[9, 17, 19]	4%

3.6.2. During Spaceflight

- Facilitating adaptation by stabilizing physiological changes to spatial conditions [4].
- Continuously monitoring internal shuttle atmosphere parameters [1, 9], oxygen supply, air quality [21], humidifying air while preventing staff exposure to aerosolized substances [27], and managing closed systems [24].
- Collaborating with other professionals in nutritional counseling [4, 9], designing dietary regimes, providing vitamin supplementation [4], and ensuring hydration [9, 23] according to nutritional requirements, intake capacity, and during EVA [21].
- Supervising proper management of body secretions for water recycling and solid waste disposal [23, 24].
- Planning, programming, and evaluating physical activities such as aerobics, flexibility, strengthening, and resistance exercises using devices like cycle ergometers, treadmills, and resistance devices to prevent musculoskeletal atrophy [22].
- Planning, programming, and evaluating the use of artificial gravity to mitigate fluid dynamics or liquid redistribution [17].
- Monitoring and evaluating the sleep-wake cycle and scheduling tasks for meditation, social activity, and work [5, 9, 23].
- Ensuring cleanliness and disinfection of the interior of the shuttle, practicing personal hygiene to prevent transmission of pathogenic microorganisms due to overcrowding [22].
- Programming and planning the use of spacesuits by assessing the functionality of the astronaut's clothing each time an EVA is performed [9, 15].
- Identify environmental hazards and manage risks to mitigate them.
- Manage information about the health conditions of the crew [4].
- Evaluation of the roadmap for unexpected medical emergencies [9].
- Provide psychological support to stabilize and improve mood and prevent defensiveness, hostility, social irritability, interpersonal conflicts, anxiety, and depression among the crew [19].
- Ensure personal privacy and reduce psychological stress through recreational activities [19].
- Promotion and prevention of healthy habits in space environments [5, 24].
- Detection, monitoring, and classification of work-related injuries or illnesses [4].
- Plan, execute, and evaluate care before identifying and classifying conditions or injuries during space missions [9].
- It plays an important role in preventive medicine programs [1], including dental hygiene, visual acuity, and hearing preservation [4, 24].
- Design prescription medication systems for administration during spaceflight, taking into account the need to pump intravenous medications rather than relying on gravity drips [21].
- Assess and evaluate the indicated medications, considering pharmacokinetics, pharmacodynamics, pharmacomicrobiomics, and the importance of their interactions for space flights [5, 19].
- Identify psychological alterations in the crew and propose strategies to maintain interpersonal dynamics and create recreational environments to manage and maintain optimal mental health [9, 15, 24].

3.6.3. After Spaceflight

- Control and monitoring of vital signs: Nurses play a crucial role in monitoring vital signs, especially body temperature and heart rate, during reentry and after spaceflight [27].
- Management of syncope and orthostatic intolerance: Nurses may monitor and control syncope (fainting) and orthostatic intolerance (difficulty adjusting to an upright position) that astronauts may experience after spaceflight [1, 4, 9].
- Musculoskeletal condition and rehabilitation: Nurses could be involved in improving the musculoskeletal condition of astronauts and providing rehabilitation, including post-landing sensorineural rehabilitation after assessment [9].
- Supply management: Nurses may ensure the replacement of supplies and report expenses for medical materials used during space missions [16].

In the future, as space exploration expands to include prolonged stays on the Moon and Mars, nurses may be required to participate in surgical procedures in space. Accidents caused by micrometeorites could result in severe trauma to astronauts, necessitating surgical interventions [34, 35]. Nurses would need to be trained in surgical techniques and participate in procedures that require instrumentation [31-33]. The development of surgical techniques based on altered gravity environments within space operating rooms would be essential for providing surgical care in space [1, 4, 9, 17, 21, 23].

Currently, nurses work in the medical facilities of NASA like the Johnson Space Center, Kennedy Space Center, and Cape Canaveral. They provide a wide range of services, especially in occupational health, not only to astronauts but also to people involved in different space programs and their families [14]. Nurses play a critical role in ensuring the health and well-being of individuals involved in space exploration.

3.7. Nursing Care Management in Space

Effective management of nursing care in space requires careful planning and consideration of the unique challenges and limitations of the space environment. Nurses must be trained to handle medical emergencies and manage patient care in the absence of gravity [1]. They must also be prepared to manage the psychological and emotional challenges that arise from being in space for extended periods. By developing specialized training programs and adapting existing nursing practices to meet the demands of space travel, healthcare providers can ensure that patients receive the best possible care, regardless of their location [1, 9]. Medical care in space is a critical issue, especially on long-duration missions where astronauts may be exposed to a variety of health risks. Nursing care management in space is crucial to ensure the health and well-being of astronauts. The evacuation system is also important in case of a medical emergency, as astronauts may need to be evacuated quickly in the event of an emergency or serious illness [5].

Gravity on Earth has had an integral effect on the development of life over billions of years, shaping the anatomy and physiology of human beings. Astronauts in space missions deal with unique hazards, including the physiological effects of microgravity, medical consequences of radiation exposure, and psychological issues linked to living in a confined, isolated, and extreme environment. Common physiological changes include a reduction in heart size and blood volume, neurological system disturbances, and decreases in bone density and muscle mass. The psychophysiological changes experienced during space missions can have undesirable health consequences and lead to operational difficulties, especially in emergencies. The human body responds to reduced gravity through different biological paths, sometimes adapting well and at other times suffering a process of deconditioning. Factors affecting the physical and mental well-being and health condition of astronauts in space include mission duration (short- *vs.* long-term), compliance in performing recommended daily exercise protocols (2h30min a day/6-days per week), consuming balanced nutrition and prescribed supplements (*i.e.*, vitamin D), and maintaining an adequate 24h awake-sleep cycle [34, 35]. More than 60 years of medical, health, and scientific knowledge already acquired from low-Earth orbital missions may not be entirely sufficient to face new space challenges, especially considering space tourism. The civilian space traveler profile will vary greatly from that of the well-selected and trained professional astronaut, imposing a range of new and more complex medical and health challenges. Furthermore, the spaceflight arena is evolving to increasingly consider longer-duration flights and potential Moon bases and Mars exploration. This raises the importance of human factors in the success of longer-term space missions and potential human off-Earth settlements [35, 36].

Telemedicine and digital health play a crucial role in space nursing. These technologies involve the use of telecommunications and technological tools for the acquisition, storage, and transmission of health data, as well as enabling virtual meetings [9, 37]. They have already been used to resolve health problems during space missions, bridging the physical distance between healthcare professionals and patients. Current digital technologies, including advanced and sophisticated artificial intelligence-based systems, will progressively be applied in space nursing, making astronauts more autonomous from the care of Earth-based doctors, health professionals, and scientists. Overall, nursing care in space requires specialized training and adaptation of existing practices to address the unique challenges and limitations of the space environment. By effectively managing medical emergencies, promoting health, and preventing diseases, healthcare providers can ensure the well-being of astronauts during space missions. The use of telemedicine and digital health technologies further enhances the provision of healthcare in space, enabling remote monitoring and virtual consultations [21, 33, 37].

3.8. Future Space Nursing Challenges

Nursing has a crucial role in the future of space exploration [19]. While there are already some advancements in this area, few nurses are currently involved due to the demanding nature of their work in different healthcare settings on Earth [14]. However, the primary purpose of the nursing profession is to provide help wherever it is needed [8]. This perspective opens up opportunities for expanding the role of healthcare during astronaut launches [38], space travel, and destinations to improve human adaptation to outer space [8, 39].

In the coming years, future generations of nurses will have the chance to educate and participate in space programs that contribute to our understanding of human responses in microgravity [9, 15, 19]. The goal is to develop new hypotheses and protocols for research-based care in space [5, 19, 40]. To achieve this, nursing education should include specific content related to space topics, enabling nurses to communicate using scientific language [1, 19, 21]. Therefore, formative education will continue to be a priority [21], requiring the evaluation and integration of curricular considerations to enhance scientific production while considering ethical aspects and public and international policies [3, 19, 38].

Although there are currently only a few nursing professionals involved in space-related research, recent recommendations from NASA's life sciences strategic planning study committee indicate the potential for more opportunities and involvement in onboard service [15, 22, 38]. Aerospace nurses working in space agencies, space research programs, or medical teams should possess extensive academic and technical training, as well as exceptional skills to provide care, conservation, and health protection in the face of unexpected medical events in space [19, 23, 24].

The integration of technology into nursing practice is a rapidly evolving field that has the potential to revolutionize healthcare delivery [39]. Information technologies, such as telehealth, are becoming increasingly important in providing healthcare services in remote and dangerous locations with limited access to medical care [1, 21]. Nurses play a critical role in delivering preventive, diagnostic, and therapeutic care to individuals living and working in isolated and extreme conditions, including closed environments, Antarctica excursions, Martian analogs (Fig. **3**), scuba diving, and space exploration [39]. In space, nurses are and will continue to be key components in providing preventive, diagnostic, and therapeutic care on the ISS, orbiting bases, the Moon, and Mars [9, 15, 21, 37]. Utilizing information technologies in nursing practice will allow for effective care management and the expansion of diverse activities that promote the development of this specialty [1, 14].

Looking toward the future, it is likely that humanity will eventually establish settlements beyond Earth, such as space cities, lunar bases, and bases on Mars [5], presenting unique environmental characteristics and health challenges. This expansion will allow humans to encounter unprecedented boundaries and unimaginable evolutionary diversity [1, 8, 10]. Additionally, the perception of time will be significantly influenced, as Mars, for example, has a day about an hour shorter than Earth and a year twice as long [8]. Nurses working on manned mission programs to send humans to these planets will need to use Earth's weather patterns as a reference point [15].

Fig. (3). a). Olympus Mission, Space Exploration Analog Habitat – Colombia (HAdEES-C). **b**) and **c**). Simulation-based training equips non-medical crew members with the necessary skills to handle medical emergencies and perform suturing, enhancing their ability to respond effectively in critical situations.

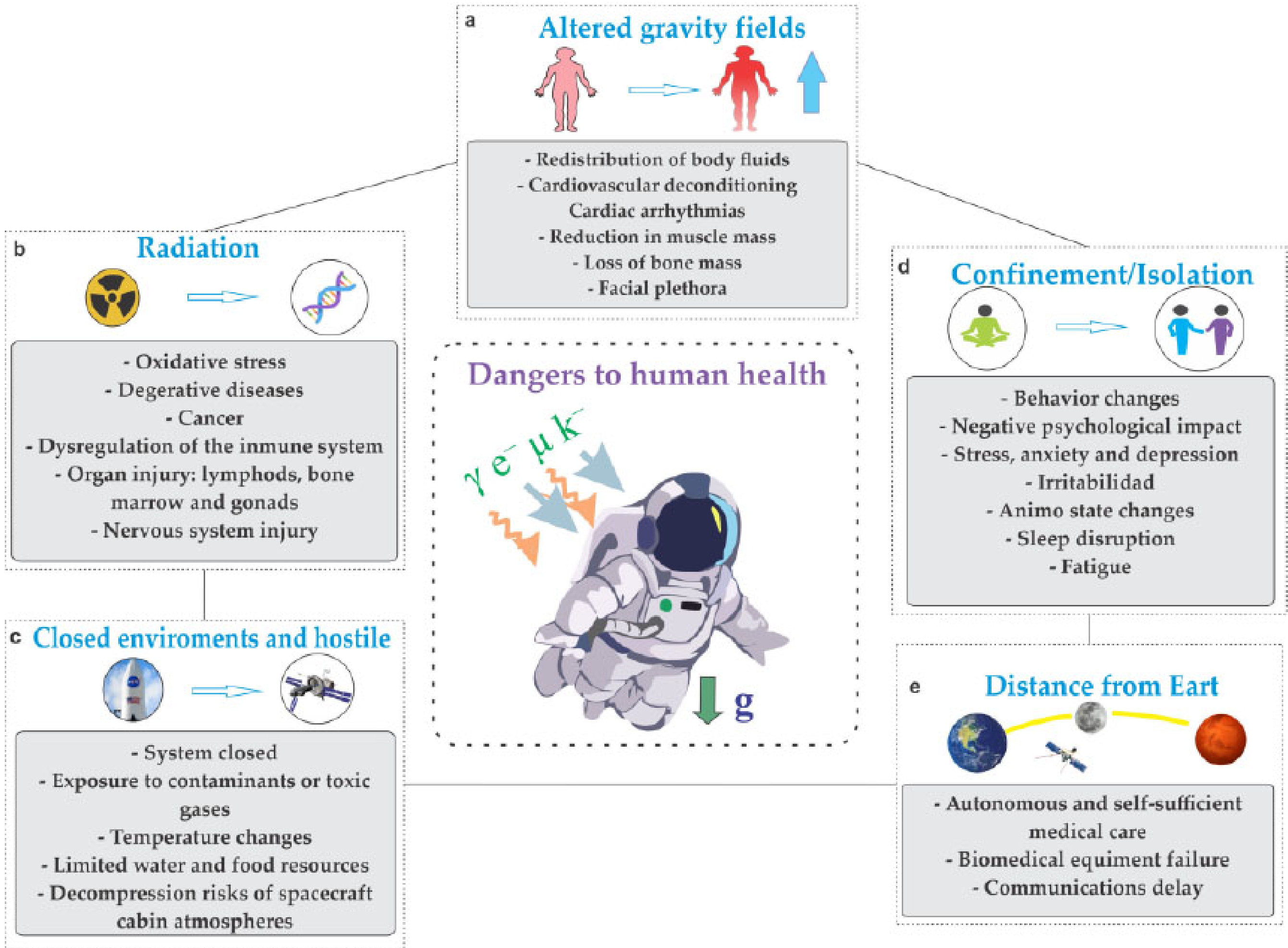

Fig. (4). Pentad dangerous to human health identified by NASA: (**a**) Altered gravity fields; (**b**) Radiation; (**c**) Hostile and closed environment; (**d**) Isolation/confinement; (**e**) Distance to Earth.

The future of space nursing presents numerous challenges and opportunities. By expanding the role of healthcare in space exploration, integrating technology into nursing practice, and preparing for the establishment of settlements beyond Earth, nurses can play a vital role in ensuring the well-being and health of astronauts and future space settlers.

4. DISCUSSION

Throughout history, care and nursing have evolved and experienced important milestones that have shaped the profession. Florence Nightingale raised the theoretical bases of care and advances in nursing as a science. Sorb [18] notes that the inclusion of nurses in aircraft crews in the 1920s marked a new era and the subsequent development of flight nursing equipped nurses with new skills. According to Symanski [15], Czerwinski *et al*. [1] Plush [14] and Butcher *et al*. [8], the participation of nurses in the medical care of astronauts during space missions began at the end of the 1950s, which highlighted the expansion of nursing functions in space exploration.

Symanski [15], Chonin *et al*. [21] and Gómez *et al*. [9] have discussed conceptual models and theories applied to spatial nursing that have played a crucial role in addressing the unique demands of the spatial environment. Nursing theorists such as Florence Nightingale, Virginia Henderson, Callista Roy, Jean Watson, Madeleine Leininger and Dorothea Orem have contributed ideas and concepts that can be applied to the care of astronauts in space. However, the most relevant was the theory proposed by Martha Rogers where the science of unitary human beings is addressed, providing valuable ideas that can be applied to the field of nursing in the context of the space age and beyond [10]. These theories emphasize the importance of creating a favorable environment [17], addressing physiological [9, 22] and psychological needs [9, 19], promoting adaptive physiological responses, recognizing the holistic nature of well-being, establishing relationships of care and considering cultural competence in nursing care [15]. The integration of multiple conceptual models and theories in nursing reflects the dynamic nature of the profession and its ability to adapt and thrive in challenging and highly dangerous environments [5].

Effective management of nursing care in space requires specialized training and adaptation of existing practices to address the unique challenges and limitations of the space environment. Cao [5] and Czerwinski *et al*. [1] believe that nurses must be prepared to handle medical emergencies and manage patient care in the absence of severity. According to Chandler *et al*. [22], Tucker [23], and Butcher *et al*. [8], they must also address the physiological, psychological and emotional challenges that arise from being in space for long periods of time [19]. Chonin *et al*. [21] suggested that continuing training programs should be developed to equip nurses with the skills and knowledge necessary to provide quality care in the space [1, 19, 21]. This includes understanding the physiological effects of microgravity, radiation exposure, and the psychological impact of living in a confined and isolated environment [3, 5, 9, 19, 23]. Likewise, Butcher *et al*. [8] noted that nurses must also receive training in the use of specialized equipment and procedures specific to space travel. In addition to medical care, nurses in space must also consider the evacuation system in case of a medical emergency. Rapid and efficient evacuation procedures are essential to ensure the well-being of astronauts in the event of a serious illness or emergency [1].

According to Gómez *et al*. [9], health care in space environments is essential for the well-being and guaranteeing optimal medical care of astronauts before, during and after space missions. So Miller [24], Raduenz *et al*. [16] and Orgill *et al*. [4] highlight that the active participation of the nurse represents an opportunity to expand the role of medical care in extreme environments such as monitoring vital signs, managing the internal atmosphere of the ship, planning physical activities, promoting healthy habits and managing medical emergencies. Likewise, it is noted that the adaptation of nursing practice to the spatial environment is essential, which requires specialized training and the integration of telemedicine and digital health technologies. Additionally, Chonin *et al*. [21], Tucker [23], and Czerwinski *et al*. [1] highlighted the importance of nursing in future space exploration, including participation in surgical procedures in space and the management of larger human settlements beyond the Earth.

CONCLUSION

In conclusion, this is the first journal manuscript developed in Latin America with the support from European supervisors covering space nursing potential innovations as a literature-review. It describes the potential it is crucial that the scientific community and space agencies collaborate with nursing professionals to expand their knowledge and understanding of nursing in space exploration. The field of Space Nursing is growing rapidly, but there is still a significant gap and need for innovation and implementation of new care protocols and modalities in microgravity environments.

The findings of this review indicate a paucity of research on the topic over time, with the majority of publications coming from the United States, followed by Latin American countries. It is necessary to promote greater scientific production in the Latin American scientific community, focusing on the effects of microgravity, physiological and psychological adaptation, and coping with stress in isolated and confined environments.

Future nursing professionals must possess extensive knowledge, skills, and risk-prevention strategies to ensure the health and safety of astronauts. Basic needs, such as communication, hazardous environments, movement and position, nutrition, and oxygenation have been addressed in the reviewed documents. Additionally, identifying hazardous pentad that may adversely affect human health in space is an important consideration, (Fig. **4**).

We strongly encourage the exchange of ideas and research collaboration between nursing professionals, the scientific community, and space agencies. This will contribute to the development of nursing theories related to space travel and the proposal of countermeasures to preserve the health of astronauts. Additionally, the benefits and advances made in space healthcare may have valuable applications on Earth (spinoffs). Space serves as a unique testing ground for technological advances and offers opportunities to mitigate orbital human factors.

By fostering collaborative links and sharing research results, the goal of making human healthcare conducive during space exploration can be achieved. It is important to engage students in this emerging discipline and provide platforms to discuss the application of terrestrial nursing methods in the context of space. As we look to the future, it is essential to prepare future generations of professionals who will interpret nursing theories as they relate to space travel and continue to advance the field.

INSTITUTIONAL REVIEW BOARD STATEMENT

The present study is an analysis of studies from public databases. The data collected is available to the public through search engines, so it was not necessary to request the consent of the authors of the different studies to analyze and present the information.

AUTHORS' CONTRIBUTIONS

The authors were involved in the origin of the idea, data collection, analysis, and preparation of the manuscript.

LIST OF ABBREVIATIONS

AsMA	=	Aerospace Medical Association
CINAHL	=	Cumulative Index to Nursing and Allied Health Literature
DeCS	=	Health Science Descriptors

EVA = Extravehicular Activities

HAdEES = Space Exploration Analog Habitat – Colombia

ICP = Increased Intracranial Pressure

IOP = Increased Intraocular Pressure

ISS = International Space Station

MeSH = Medical Subject Headings

NASA = National Aeronautics and Space Administration

QCRI = Qatar Computing Research Institute

SciELO = Scientific Electronic Library Online

SLS = Space Launch System

SMS = Space Motion Sickness

SNS = Space Nursing Society

U.S. = United States

USA = United States

WoS = Web of Science

CONSENT FOR PUBLICATION

The authors provide signed consent by the participants appearing in Fig. (3) to use the images for literature review.

AVAILABILITY OF DATA AND MATERIALS

The data set used and/or analyzed during the current study is available from the corresponding author [M.V-R] upon reasonable request.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

Appendix A. Analysis of the characteristics of included articles.

No.	Autor	Title	Purpose or Content	Document Type	Language	Place/Year
1	Tucker [23].	Childbearing in space. A theoretical perspective	The purpose of the article is to motivate creative nursing thinking. The possible gestation and physiological interactions of the human body in microgravity environments are discussed.	Journal article	English	Galveston, USA – 1967
2	Syner [2].	Science and technology in space nursing	It shows nursing as a profession with the ability to move parallel with the advancement of science and technology. It addresses issues associated with the diversity and recording of physiological activities of the body through the use of computational technology to generate medical information.	Journal article	English	Colorado, USA – 1967
3	Hutchins [26].	Orientation of the aerospace nurse to occupational health	It is an article of experience about occupational health in an aerospace nursing course, where it evidences the importance of teamwork, and the development of competencies and skills to preserve a health and safety team.	Personal Experience Article	English	USA – 1968
4	Perrin [38].	Space nursing. A professional challenge	The article presents the role of nursing and man's adaptation to space, physiological and psychological changes, human-machine duality, and curricular evaluations of space nursing and raises the challenges as a collaborating team in the era of space exploration.	Journal article	English	USA – 1985
5	Shorb [18].	An update: the flight nurse section--its past, present, and future	The article presents a chronological account of the past, present, and future of flight nursing and its participation in the different Aerospace Medicine programs.	Journal/Historical Article	English	USA – 1985
6	Polk-Walker [17].	Aerospace nursing: the new frontier	The purpose of the document was to narrate the contributions of nursing in the field of space exploration from ancient times to the present. It analyzes the physiological and psychological changes of human beings with a focus on the needs, roles of nursing, and the negative impact of space on the health of astronauts.	Journal article	English	USA – 1989
7	Chandler [22].	Health problems in the extraterrestrial environment	This is a review of the physiological and psychological changes associated with spaceflight and the role of nursing in space.	Journal article	English	New York, USA – 1989
8	Barrett EA [20].	Space Nursing	It is an article with a visionary approach by Martha Rogers on the importance of expanding nursing services beyond the planetary level. In addition, it addresses the general effect of the changes that astronauts and future inhabitants of space will experience.	Journal article	English	Nueva York, USA – 1991

No.	Autor	Title	Purpose or Content	Document Type	Language	Place/Year
9	Miller [24].	Nursing in space: a new frontier for nursing	The article describes outer space as a scenario that will test the intuition and ingenuity of the various scientific areas, especially nursing.	Journal article	English	USA - 1991
10	Butcher HK [8].	The overview effect: the impact of space exploration on the evolution of nursing science	The purpose of this article was to explore the general effect, the experience evoked by space travel that can transform the patterns of human existence. It addresses nursing paradigms and the vision of an evolutionary universe.	Journal article	English	Columbia, USA – 1992
11	Burge [19].	Living and working in space: evolution of nursing in a new environment	This article shows the cosmos as an opportunity to develop non-invasive health technologies. It also addresses the main human risks and responses, the role of nursing in space, the main physiological and psychological changes, space education for nursing and technological contributions to enabling human existence.	Journal article	English	Alabama, USA – 1992
12	Chonin [37].	Telehealth: important concepts for future nursing practice in space environments	Discusses the implications of telehealth in remote and hazardous environments. It provides to know the importance of the era of communication for health professionals, especially for nurses.	Journal article	English	North Miami Beach, USA – 1998
13	Czerwinski [1].	Nurses' contributions to the US space program	It addresses the main contributions of nursing in space programs. Likewise, it proposes nursing as part of the medical care team during spaceflights.	Journal article	English	Rochester, USA – 2000
14	Symanski [15].	A nurse on Mars? Why not?	This article develops basic aspects about the past, present and future of space nursing. Nursing as a multidisciplinary team, formation of the space nursing society, identification of potential risks to human health and main theories.	Journal article	English	Orono, USA – 2000
15	Plush [14].	Origins, founding, and activities of the Space Nursing Society	The article exposes the origin and establishment of the space nursing society through a brief discussion on the history that led to its participation in the space program and the main contributions as a profession in collaboration with other professional groups.	Journal article	English	New York, USA – 2003
16	Chonin [21].	Pediatric nursing in space environments	Article whose purpose is to explain the growth and development of the human beings in extraterrestrial conditions that will allow to expand nursing activities for many generations in the space field.	Journal article	English	USA – 2004
17	Schweitzer [40].	Nursing care protocol for trauma patients in the aerospace environment - during and post-flight care	This study aimed to present a protocol for nursing care in the pre-aerospace removal of adult trauma victims. The protocols will serve safer nursing care for airborne patients.	Original article	English	Florianopolis-SC, Brazil - 2012
18	Gómez Ayala [9].	Care in space. Space Nursing	This is a documentary research based on various bibliographic sources whose objective of the book was to implement and propose a systematic assessment with a focus on the basic needs of astronauts and health care of the nursing professional in microgravity conditions.	Book	Spanish	Mexico – 2018
19	Orgill [4].	Effects of human spaceflight and nursing care for its prevention	The objective was to know through scientific evidence the effects of human spaceflight and the preventive role of nursing in the mission, to know human factors, risk factors and to know the problems that exist for each sex.	Literature review article	Spanish	Lleida, Spain -2018
20	De Pin Raduenz [16].	Nurses' responsibilities in the aerospace environment	The objective was to characterize nurses working in the aerospace environment and identify the most frequent assignments developed by them during the pre-flight, flight and post-flight periods. The nurse's performance in the aerospace environment predominates organizational actions and care for the victim during all stages of the flight.	Original article	English	Catarina, Brazil - 2019
21	Morais [27]	Role of aerospace care nursing in Brazil: Integrative review	This study examines the role and challenges of nursing professionals in aerospace transportation in Brazil. With a focus on prehospital care and the ABCDE system. The authors conclude that further studies are needed to fill the existing knowledge gaps in aerospace nursing.	Review article	English	Brazil - 2021
22	Pandian [3].	Nursing Care in Space—The need for nurses in the new and evolving field of healthcare in space	It addresses the advances of space exploration, physiological changes, the present and future of space nursing. Likewise, it briefly explains the need to design and develop health care policies for humans in space.	Editorial	English	Maryland, USA – 2022

No.	Autor	Title	Purpose or Content	Document Type	Language	Place/Year
23	Cao Xinhua [5]	Research progress on the effects of microgravity and space radiation on astronauts' health and nursing measures	The article analyzes the health of astronauts in relation to the effects of microgravity, space radiation, geometry and the orbit of space stations. Various nursing measures have also been investigated to address these effects.	Research article	English	Xi'an, China - 2022

Source: Original contribution.

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