*BRIEF COMMUNICATION * KURZBERICHT * COMMUNICATION CONCISE*

ANTHROPOLOGIE LXII/1 • 2024

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THE SOJUZ 11 MISSION: RECONSTRUCTION OF A UNIQUE CASE OF ASTRONAUTS WHO DIED IN THE COSMIC SPACE DUE TO DECOMPRESSION ILLNESS

ABSTRACT: Space represents the vacuum existing between celestial bodies. By convention, it is located at an altitude of 100 km above sea level. Space exploration is one of the greatest human challenges today. The first space missions were carried out starting from the 1960s. Since then, dozens of other missions have followed, with increasingly complex objectives. Incidents occurred during various launch and landing procedures. However, only one case of death has occurred in space and not in the Earth's atmosphere. This is the case of the Soyuz 11 mission, which took place in 1971. The case is unique since the three cosmonauts, present in the mission were, due to a technical failure, exposed to the cosmic vacuum for an interval of 700 seconds. The purpose of the work is to reconstruct from a forensic point of view what were the factors that caused the death of the three astronauts. The case emphasizes the role of pressurization safety measures in view of the next missions in space.

KEY WORDS: Forensic pathology – Death – Cosmic space – Decompression illness – Barotrauma – Vacuum

INTRODUCTION AND RESEARCH METHODOLOGY

The Universe is defined as that place where everyone and everything exists. More precisely, it constitutes the whole of all existing matter, energy, planets, stars and galaxies (Caputo *et al.* 2020, Morabito, Silk 2021). Space exploration has always represented the symbol of the unknown, fascinating humankind and science for centuries, becoming a goal that is not only desirable but also concretely achievable. In parallel with the advancement of aerospace technologies and knowledge

Received 27 June 2023; Received in revised form 4 September 2023; Accepted 4 September 2023. Available online 28 February 2024.

DOI: https://doi.org.10.26720/anthro.23.11.13.1

in the fields of aeronautics and astrophysics, numerous space missions have been planned, starting from the second half of the 20th century. The first flight with an animal on board was the famous case of dog Laika who was launched in Sputnik 2, in 1957, and who lost her life during the journey (Meijer, Feigenberg 2000, West 2001). However, this episode did not stop scientific research. In 1961, cosmonaut Jurij Gagarin was the first man in history to fly into space, going into orbit on the Vostok 1 ship at a height of 315 km, and to return safely to Earth (Skoog *et al.* 2002). Since then, dozens of space missions have been carried out with humans aboard both inside and outside of Earth's orbit. Over the course of history, several death episodes have been documented that occurred accidentally during launch procedures, landing and in various space simulations. Nevertheless, only one death episode actually occurred in space and not in the upper Earth atmosphere. In the forensic literature, to date there are no comprehensive studies that have ever evaluated what are the factors determining the human death in space. Below we report the case of the space disaster of the Soyuz 11 spacecraft, which occurred in 1971, in order to analyze from a forensic point of view what are the chronology, dynamics and manner by which death in cosmic space occurs. The case was reconstructed through research on websites, books that dealt with the accident and historical newspaper articles from that time.

CASE DESCRIPTION

We report the case of the Soyuz 11 space mission. It was part of the so-called Soyuz Program, that is a series of space missions whose initial aim was to land man on the Moon. Specifically, the aim of the Soyuz 11 mission was to reach and lock onto the Soviet space station Saljut 1, launched into orbit in April 1971, and to bring astronauts on board. On June 6, 1971, the final launch of the mission took place from the base located in the Baikonur cosmodrome, in Kazakhstan. The crew consisted of three cosmonauts: Dobrovol'sky, who was the commander, and two engineers, Patsayev and Volkov. Soyuz 11 is remembered as the first mission in history in which the definitive docking to a space station was successfully completed with the passage of cosmonauts inside the station. The crew remained in the station for three weeks with the task of testing the systems of Saljut 1 and carrying out some scientific experiments (Ivanovich 2008, Staff Writers 2013). Due to a technical problem, the return to Earth was brought forward by a week. However, a fatal accident occurred during the re-entry procedure. In fact, at the time of the detachment of the Soyuz from the space station, a valve broke; it was crucial for the adjustment between the internal and external pressure of the spacecraft, but it should have opened only shortly before landing. The ship was at an altitude of 168 km and none of the three astronauts was wearing the suits at that moment. Since then, the cabin underwent an abrupt depressurization (Ivanovich 2008, Staff Writers 2013, Ezell, Ezell 1978, Kendall 2021).

The constant loss of pressure became fatal within 30 seconds, without the astronauts being able to intervene. In particular, the on-board recorders documented that 50 second after the detachment of the orbital module, Patsayev's heart rate had dropped to 42 beats per minute, and 110 seconds after the accidental opening of the valve all three cosmonauts were dead. The cabin gradually reached the pressure of 0 and remained so until the ship reached the Earth's atmosphere. The cosmonauts were subjected to the vacuum for a total duration of about 700 seconds. Despite the technical failure, the ship still reached Earth, thanks to the automatic landing system (Ivanovich 2008, Staff Writers 2013, Ezell, Ezell 1978, Kendall 2021).

Upon landing in the Qaraghandy Region of Kazakhstan on 30 June 1971, the recovery teams went to the capsule unaware of the incident. In particular, the spacecraft had landed on Earth perfectly, as had been predicted. The three cosmonauts were found sitting on their chairs, with signs of cyanosis, otorrhea and nosebleeds. Therefore, resuscitation maneuvers were attempted on the three men in vain. The landing of the cosmonauts, with the resuscitation attempts, is documented by a large number of photos and videos easily available on the Internet.

In the following days, various hypotheses were formulated on the cause and dynamics of death, documented by numerous newspapers of the time. An autopsy was performed. The medical examiners described a cerebral hemorrhage with tympanic perforation and bleeding in the inner ear and nasal cavity. The toxicological analysis performed also showed that there were no traces of nitrogen in the blood; it, together with other gases such as oxygen, had gone into the circulation in the form of gaseous emboli causing the rupture of the vessels. An increase of lactic acid was found in the blood. The cause of death was therefore attributable to barotrauma with phenomena of gaseous ebullism (Ivanovich 2008, Staff Writers 2013, Ezell, Ezell 1978, Kendall 2021).

It was the first and only time in the history of space exploration that a crew died in space.

DISCUSSION AND CONCLUSIONS

Cosmic space can be defined as the vacuum existing between celestial bodies. Space is "almost empty" because it is made up of a density, albeit very low, of matter. In fact, gas particles travel in it, but also electromagnetic radiation and magnetic fields (Buser 2000). The density of matter present is concentrated in a few hydrogens' atoms / cubic meter. This phenomenon is mainly determined by the aggregation of the matter of the Universe, due to gravity, in celestial bodies, such as planets, stars and galaxies (Andrulis 2011, Chaisson 2014). Due to the force of gravity, moreover, on the Earth there is a gas envelope that envelops the surface of the planet, that is, the atmosphere. There is no real boundary between space and the Earth's atmosphere. By convention, the International Aeronautical Federation has defined the height of 100 km, known as the Karman line, from sea level as the starting point of space. Further away from the Earth, density tends to decrease and the vacuum to increase, approaching absolute vacuum, understood as the total absence of matter. Exposure to vacuum is a deadly phenomenon for humans. This is correlated to the pressure, equal to 0. This phenomenon is at the basis of a traumatic pathology occurring in people who are subjected to rapid changes in pressure, namely barotrauma (Aquila *et al.* 2018). Barotrauma is damage to the body's tissues generated by the pressure difference between the body and the environment. Although in the literature most of the scientific work is focused on hyperbaric damage, i.e. those injuries associated with an increase in pressure (as in diving), in reality barotraumas can also be caused by hypobaric mechanisms, i.e. by exposure to low pressures (as occurs at high altitudes). By Boyle's law, the volume of a given mass of gas is inversely proportional to its pressure, if the temperature remains constant. Therefore, in an enclosed space containing a gas (such as the pulmonary alveoli), the volume of this gas increases as the pressure decreases. In the case of pulmonary involvement, this increase causes pulmonary overdistension and rupture of the alveoli themselves with passage of gases in different anatomical sites: mediastinum, pleura, subcutis, arterial vessels (Inman *et al.* 2020, Diaz, Heller 2021). The increase in volume may be such as to generate traumatic phenomena such as pneumothorax and pneumomediastinum. Barotrauma can also cause extensive damage to the middle ear, sinuses, teeth, gastrointestinal system or can also cause pulmonary hemorrhage and subcutaneous emphysema (Oneill *et al.* 2021). In these conditions, the gases present (in our body) can penetrate the tissues or embolize through the blood vessels. Embolization causes ischemic lesions. The tissue most sensitive to ischemia is the nervous one and arterial cerebral gas embolism can be fatal. These phenomena are part of the *pulmonary overinflation syndrome* (Hamilton-Farrell, Bhattacharyya 2004). With the term decompression illness, we indicate two different phenomena that underlie the same pathology: 1) decompression sickness, which includes a series of signs and symptoms caused by the formation of gas bubbles; 2) overexpansion injuries, caused by the expansion of gases as the pressure decreases (Hamilton-Farrell, Bhattacharyya 2004). These low-pressure events are related to the phenomenon known as ebullying. Ebullying is the transformation of water from a liquid state to a vapor state by boiling, when the ambient pressure is 47 mmHg or less (Murray *et al.* 2013). This phenomenon occurs when the height of 60,000 feet (approximately 11.4 miles), known as "Armstrong's Line", is exceeded (Tarver *et al.* 2018). In fact, we know that the boiling point of water is equal to 100 ° C only when the pressure is equal to that of the sea level (1 atm). However, as the pressure decreases, the boiling point tends to decrease progressively, until it boils completely and at any temperature in a vacuum. Considering that water makes up 70% of the human body, all the humid parts of the body would be immediately affected. Symptoms are related to dehydration with evaporation of physiological fluids present on the eyes, mouth, tongue, skin, and arterial gas embolism.

The case reported is unique as the three astronauts were at a height of 168 km from Earth and none of the three was wearing pressure suits at the moment of the accident. Thus, the case clearly demonstrates what happens when a subject is suddenly exposed to space. The case shows that the conditions quickly proved fatal. While it is not possible to determine with certainty for how many seconds the three men remained conscious, the vital signs recorded show that after 50 seconds the frequency had dropped to 42 bpm and after 110 seconds all three astronauts were dead. Therefore, it is possible to assume that the three astronauts remained conscious for the first 15 seconds at most.

From a forensic viewpoint, we consider that in space there are at least three physical factors that impede the survival of a human. They are: 1) lack of oxygen; 2) the temperature; 3) the vacuum or the pressure equal to 0.

As regards the absence of oxygen in space, it was not the primary cause of the death of astronauts since death occurred in too narrow an interval to be able to determine the death. In fact, a man can survive in conditions of apnea even for a time greater than 110

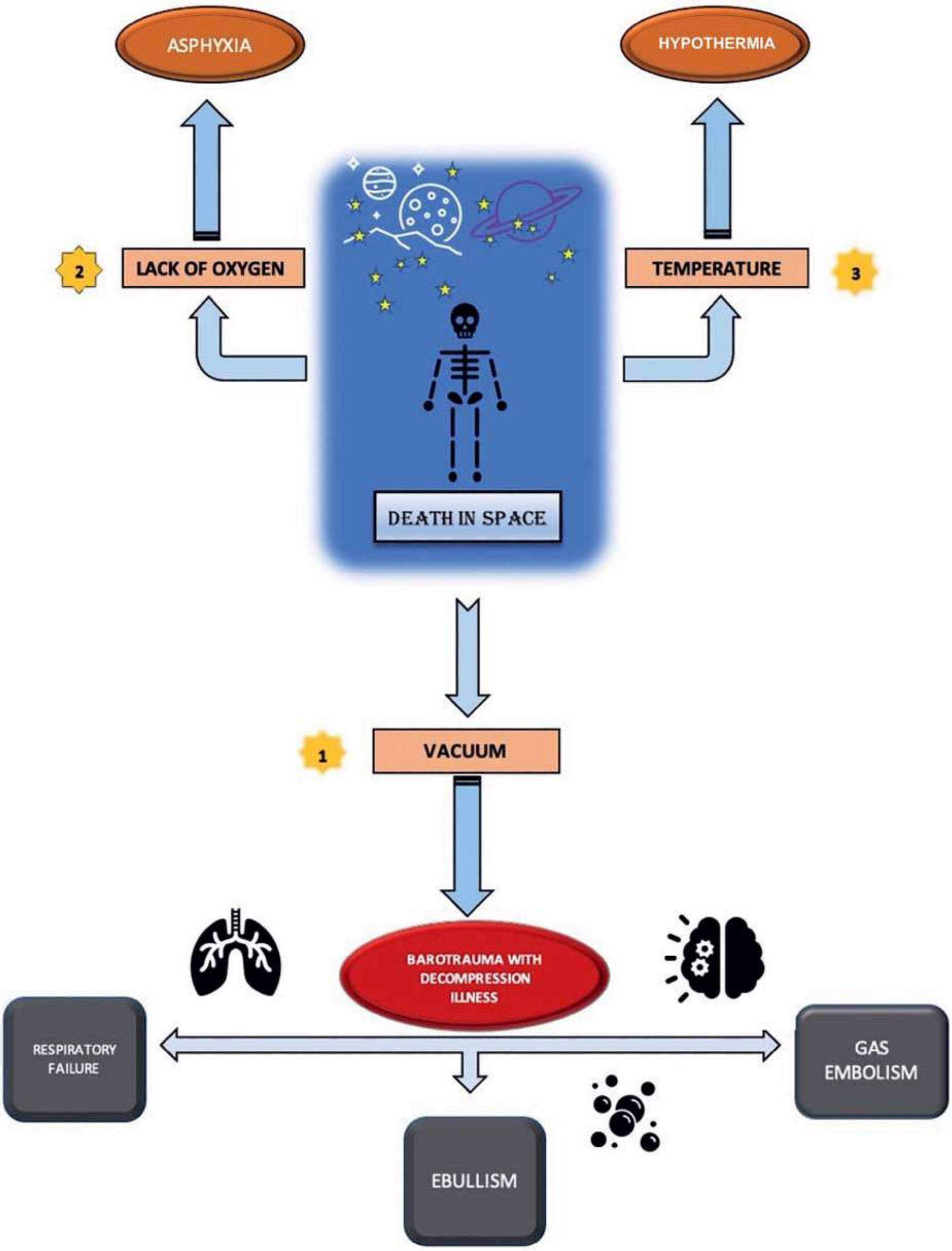

FIGURE 1: Physiopathology of death in space with analysis of physical factors that do not allow human survival.

seconds. As far as the temperature is concerned, it is still possible to exclude this hypothesis. In fact, the temperature in space is close to absolute zero (-273 K). Whatever the temperature was, the heat exchange between the human body and the external environment in the vacuum does not occur according to the physical phenomena of conduction or convection but occurs by radiation. Radiation is the transfer of thermal energy between two bodies by means of electromagnetic waves. This is the only phenomenon of thermal energy exchange that can also occur in a vacuum. However, even the heat exchange by radiation takes considerably longer than 110 seconds to determine death. Therefore, as demonstrated by the autopsy, it can be affirmed that the three men died primarily due to cardiorespiratory insufficiency caused by the rapid barotrauma generated by the vacuum to which they were subjected, with concomitant phenomena of ebullism and arterial gas embolism (Ivanovich 2008, Staff Writers 2013). This phenomenon would also justify the absence of gases such as oxygen and nitrogen in the blood. The forensic investigations conducted in these cases can also include the histological examination, which documents the rupture of the interalveolar septa and the presence of emphysematous bubbles, and the analysis of gases taken from the body cavities, which normally do not contain them, such as example in the heart chambers (*Figure 1*). Furthermore, in recent years, thanks to the advent of virtopsy, it is possible to document the presence and distribution of the gaseous collections present in the organism (Aquila *et al.* 2019).

The reported case is unique in history, both because it is the only case of death that occurred in space and because the bodies returned to Earth. This made it possible to document with certainty what were the cause and manner of death of a human in space, i.e. the hypobaric decompression with ebullism to which the body is subjected due to exposure to vacuum. After the accident, the Soyuz capsule was redesigned; in addition, a new pressurized suit was created to wear on return (Solok-K). The crew would also have dropped from three to two cosmonauts. The Apollo 15 lunar mission, scheduled for a few weeks later, was also changed: the astronauts had to wear pressurized suits during take-off from the Moon, and the entire structure of the capsule was re-examined. Since then, no astronauts have died due to the phenomena of exposure to the vacuum in space. We point out that the case reported is still highly relevant today. In particular, we emphasize the importance of respecting the pressurization measures and systems during missions. These rules are crucial for the safety of astronauts especially considering the upcoming aerospace challenges that await us, such as the return of man to the Moon and the first human exploration of the planet Mars (Foster, Butler 2009).

From a forensic point perspective, the following diagnostic protocol in cases of deaths in space can thus be suggested:

- pre-autopsy radiological investigation with CT angiography: this study is already used in cases of barotrauma to evaluate gas bubbles, trauma of the alveolar septa, emphysema;
- detailed macroscopic evaluation of the vessels at autopsy with observation of any bubbles;
- accurate macroscopic and microscopic study of lungs and heart;
- evaluation of thermal energy or precipitation injuries, correlated to potential accidents occurred during the procedures;
- microscopic analysis of blood smears, useful for examining any changes in the morphology of red blood cells caused by pressure stress, with an examination of sodium and potassium levels.

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