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EPIDEMIOLOGICAL ANALYSIS OF COSMONAUT MORTALITY: 1960–2023

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Introduction. Cohort analytical epidemiological studies of cosmonauts' health have a number of specific features. The estimates of long-term health outcomes in this occupational group can only be refined provided that the observation period of the Soviet and Russian cosmonaut cohort, originally established in 2013, be extended and regularly updated with emerging data.

Objective. Analysis of changes in the main mortality indicators of Soviet and Russian cosmonauts over the cohort observation period extended by five years until 2023.

Materials and methods. Using prospective observation studies over the historically formed cohort of male Soviet and Russian cosmonauts in 1960–2023, data update was implemented. Encoded and anonymized personal data of cosmonauts underwent processing and analysis. Using the standardized mortality ratio (SMR) with a 95% confidence interval (95% CI), mortality risk among cosmonauts was assessed. The total number of participants as of the cohort closure date (31.12.2023) was 270 cosmonauts, divided into two groups based on the presence of spaceflight (SF) experience. Group 1 comprised 127 cosmonauts (47.0%), who undertook at least one SF. Group 2 comprised 143 cosmonauts (53.0%) without SF experience (internal control). The male population of Russia served as the external control group. Cause-of-death analysis was conducted according to ICD-10. Additionally, information on the initial education of cosmonauts as a factor significantly influencing life trajectory was collected. Statistical processing was carried out using the MS and Stata 14 software packages.

Results. Extending the observation period contributed to an increased accuracy of death risk metrics by narrowing the 95% confidence intervals. The all-cause mortality risk among cosmonauts with SF experience was found to be reliably lower compared to both the male population of Russia (SMR = 0.37; 95% CI 0.27–0.50) and cosmonauts without SF experience (SMR = 0.73; 95% CI 0.53–0.98). No statistically significant decrease in cancer-related death risk was observed among cosmonauts with SF experience compared to the general population (SMR = 0.62, 95% CI 0.32–1.09). A correlation was found between the initial education of cosmonauts and mean age at death. Thus, the mean age of death for cosmonauts with military specialization and SF experience was 68.1 years, compared to 60.3 years (p = 0.015) for those without SF experience.

Conclusions. Oncological vigilance in cosmonauts with SF experience is generally higher than in both control groups, despite their unequivocally better health status. Further refinement of the data obtained can only be achieved by extending the observation period, considering the career-long duration of space stay in relation to the health status of cosmonauts. Individual-related factors affecting the health of cosmonauts without SF experience were identified. The link between professional education and the mean age at death underscores the need for developing individual preventive measures for this group and longer post-career health monitoring.

Keywords: cosmonauts; space flight; mortality; cohort studies

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ЭПИДЕМИОЛОГИЧЕСКИЙ АНАЛИЗ СМЕРТНОСТИ КОСМОНАВТОВ: 1960–2023

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Введение. Когортные аналитические эпидемиологические исследования состояния здоровья космонавтов имеют ряд особенностей, связанных со спецификой изучаемой профессиональной группы. Уточнение отдаленных показателей здоровья можно ожидать только при условии расширения периода наблюдения за когортой космонавтов СССР и России, впервые сформированной в 2013 г., с систематическим обновлением расчетных данных.

Цель. Анализ изменений основных показателей смертности отечественных космонавтов при 5-летнем расширении периода наблюдения за когортой до 2023 г.

Материалы и методы. С применением проспективного наблюдения за исторически сформированной когортой космонавтов СССР и России мужского пола за период с 1960 по 2023 г. выполнено обновление данных, с помощью показателя стандартизованного относительного риска (СОР) с 95% доверительным интервалом (95% ДИ) оценен риск смерти космонавтов. Проведены обработка и анализ закодированных и обезличенных персональных данных космонавтов. Общее количество участников на дату закрытия когорты (31.12.2023) составило 270 космонавтов, разделенных в зависимости от наличия опыта космического полета (КП) на две группы: группа 1 — 127 человек (47,0%), космонавты, совершившие хотя бы один КП; группа 2 — 143 человека (53,0%), космонавты, не имеющие опыта КП («внутренний контроль»). Мужское население России принято за «внешнюю» контрольную группу. Анализ причин смерти проведен по укрупненным классам болезней в соответствии с МКБ-10. Дополнительно собрана информация об исходном образовании космонавтов как фактора, значительно влияющего на траекторию жизни. Статистическая обработка произведена с использованием пакета программного обеспечения Microsoft Office и программного обеспечения Stata 14.

Результаты. Увеличение периода наблюдения способствовало повышению точности показателей риска смерти космонавтов за счет сужения 95% ДИ. Риск смерти космонавтов, совершивших космический полет (КП), от всех причин смерти в совокупности достоверно ниже при сравнении как с мужским населением России (СОР = 0,37; 95% ДИ 0,27–0,50), так и с космонавтами без опыта КП (СОР = 0,73; 95% ДИ 0,53–0,98). Получено отсутствие достоверного снижения риска смерти космонавтов, имеющих опыт КП, от злокачественных новообразований при сравнении с населением (СОР = 0,62, 95% ДИ 0,32–1,09). Показано наличие связи между исходным образованием космонавтов и средним возрастом смерти: средний возраст смерти космонавтов — военных специалистов, имеющих опыт КП, составил 68,1 года, не имеющих опыта КП — 60,3 года (p = 0,015).

Выводы. Для космонавтов, совершивших КП, сохраняется общая онкологическая настороженность, несмотря на однозначно лучшее состояние их здоровья при сравнении с обеими контрольными группами. Уточнение полученных данных может быть достигнуто только при расширении периода наблюдения, в том числе за счет увеличения времени, проведенного в космосе за карьеру, в зависимости от жизненного статуса космонавтов. Обнаружено наличие внутренних факторов, влияющих на здоровье космонавтов без опыта КП: связь между профессиональным образованием и средним возрастом смерти говорит о необходимости разработки индивидуальных профилактических мероприятий для этой группы лиц, а также углубленного наблюдения за состоянием их здоровья после завершения карьеры.

Ключевые слова: космонавты; космический полет; смертность; когортные исследования

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INTRODUCTION

Cohort analytical epidemiological studies are generally applied for assessing causal relationships between exposure to negative factors and health outcomes in a specific risk group [1]. Cohort studies possess a number of undeniable strengths, including high ethical safety due to the absence of active intervention in the participants' lives and low susceptibility to systematic errors due to strict data collection protocols and the application of powerful statistical analysis methods. However, their implementation is associated with a significant drawback related to the necessity for a long-term observation of the studied group [2]. Depending on the research objective (e.g., morbidity or mortality assessment), the duration of observation for a risk population can range from several years to several decades, driven by the need to record the studied events in a sufficient number of participants to achieve statistical significance of the results.

Cohort studies of the health status of cosmonauts face additional challenges. First, the relatively small number of individuals under observation can, on one hand, reduce the statistical power of analysis, but, on the other, decrease the likelihood of losing cohort participants. Second, the unique health requirements, multistage professional selection, lifestyle specifics, and socioeconomic status — all these factors impose special demands on the selection of a representative control group. Third, such studies are specific in terms of analyzing exposure time to adverse occupational conditions. In other professional groups, exposure is typically equal to the length of service; however, for cosmonauts, it is the duration of space stay over their career, which is much shorter than their total service record. Further development of manned spaceflight implies a constant increase in the duration of space missions, which extends the necessary observation period for such cohorts in analytical epidemiological studies. Fourth, access to some data is restricted and there are difficulties in tracking life trajectories after the end of a cosmonaut's career.

Space flights (SF) place immense physiological and psychological demands on the human body, making assessment of their long-term consequences a critical aspect of further space exploration [3, 4]. In this connection, in 2013, a large-scale cohort analytical study was initiated to cover a 53-year observation period of the cohort of USSR and Russian cosmonauts (1960–2013) [5]. This work was the first attempt to analyze mortality among cosmonauts, both those who had flown to space and those who had not, becoming an important step in understanding the long-term effects of the complex impact of SF factors. However, as argued above, a comprehensive analysis can only be achieved by ensuring the continuity of the observation period and regularly supplementing emerging data.

In 1992, a long-term health monitoring program for astronauts was launched in the USA, entitled "Lifetime Surveillance of Astronaut Health" (LSAH). This program involves regular surveillance of morbidity and mortality, regularly updating the results obtained. The most complete study of astronaut mortality, covering the 1959–2017 period, was published in 2018 [6]. In 2021, this research was supplemented with a special focus on mortality from malignant neoplasms [7]. The experience of long-term continuous monitoring of the astronaut cohort demonstrates the validity and applicability of this approach. Further, monitoring of the international cohort of astronauts from EU countries, Canada, China, and Japan has been initiated [8], the results of which can be evaluated in the future.

Given the rarity of the studied event (mortality), updating the data every five years can be considered advisable. The previous update of the formed cohort of USSR and Russian cosmonauts was performed in 2018 (covering a 58-year period). In this work, we aim to analyze changes in the main mortality indicators in the cohort of USSR and Russian cosmonauts with an extended observation period by five years, until 2023 (in total, covering a 63-year period).

MATERIALS AND METHODS

The research was conducted by extending the observation period of the historical (retrospective) cohort of male cosmonauts by five years and its updating with new data. This cohort was first formed in 2013 and updated in 2018 [5, 9]. The observation period was extended until 31.12.2023 and updated with new death cases, person-years of observation, and data on new cosmonauts selected into the corps in 2018 and 2020. The total observation period was 63 years (1960–2023).

The sources of information on USSR and Russian cosmonauts were archival materials from the Medical Directorate of the Gagarin Research and Test Cosmonaut Training Center, archival materials from the Institute of Biomedical Problems of the Russian Academy of Sciences, and the open digital database "Roscosmos."[1] The primary criterion for including cosmonauts in the study was the completion of basic space training.

The cosmonauts' personal data were coded and anonymized. The total number of participants at the cohort closure date (31.12.2023) was 270 cosmonauts, who were divided into two groups based on space flight (SF) experience:

- Group 1 — 127 individuals (47.0%), cosmonauts who have completed at least one SF;
- Group 2 — 143 individuals (53.0%), cosmonauts without SF experience (internal control).

The relative numerical stability of the second group should be noted, which is due to parallel changes in the compositions of the cosmonaut groups: the enrollment of new cosmonauts into the corps and their transition from the second to the first group after completing a SF.

The main characteristics of the cohort are presented in Table 1.

Each cosmonaut was observed from the date of enrollment as a trainee in the corps and followed either until the date of death (for deceased individuals) or until the cohort closure date (31.12.2023). For a small portion of cosmonauts (from Group 2), the vital status could not be determined (2.8%), which allowed the study to continue by excluding them from the analysis.

The analysis of causes of death was conducted according to the following broad classes of diseases in accordance with the International Classification of Diseases, 10th Revision (ICD-10):

- malignant neoplasms (MN, C00–C97);
- diseases of the circulatory system (DCS, I00–I99);
- external causes, such as accidents during aviation and space flights, etc. (V01–Y98);
- other causes (not belonging to the specified classes, e.g., diseases of the endocrine system, diseases of the digestive organs, etc.);
- all causes combined.

The combination of all causes, excluding external ones, was taken as natural causes of death.

To identify additional factors that may have influenced cosmonaut mortality, information about their basic education was collected. Participants were assigned the following attributes:

- "Military specialist" — those who graduated from any military aviation school or college (for military pilots and navigators), as well as those who graduated from a military educational institution with an engineering specialty (for military engineers);
- "Engineer" — those who graduated from any civilian educational institution with one of the engineering specialties;
- "Other profession" — those who received other education, e.g., physician, journalist, biologist, etc.

The general characteristic of the cohort in terms of education is presented in Table 2.

The overwhelming majority of military specialists (pilots, navigators, and engineers) among cosmonauts in both groups is explained by the specifics of cosmonaut selection in the USSR. Then, selections were mainly conducted as closed departmental competitions, only occasionally supplemented by small thematic targeted recruitments (e.g., the selection from the USSR Academy of Sciences for filming a feature film aboard the *Mir* space station, the "Space is for Children" program, etc.). It was only in 2012 that

[1] Digital database of the state corporation for space activities "Roscosmos". URL: http://www.roscosmos.ru/

Table 1. Vital status and age characteristics of the studied cosmonaut cohort, 1960–2023

Vital status	Group 1 *n* = 127		Group 2 *n* = 143		Total *n* = 270	
	n	%	*n*	%	*n*	%
Living	82	64.6%	69	48.3%	151	55.9%
Deceased	45	35.4%	70	49.0%	115	42.6%
Unknown	0	0.0%	4	2.8%	4	1.5%
Total	127	100%	143	100%	270	100%
Mean age of cosmonauts, years						
Mean age of cosmonauts (years) at the time of	***M ± SD***		***M ± SD***		**Statistical significance level, *p***	
Selection	31.2 ± 4.9		31.6 ± 5.9		0.544	
Living	63.9 ± 13.6		70.1 ± 16.6		0.007	
Deceased	67.7 ± 15.1		61.7 ± 15.3		0.021	

Table compiled by the authors based on their own data

Note: *n* — cosmonaut number; *p* — level of statistical significance; data are presented as mean value and standard deviation of the mean *M ± SD*.

Table 2. Initial education of cosmonauts

Initial education	Group 1		Group 2		Total	
	n	%	*n*	%	*n*	%
Military specialists, of which:	71	55.9%	86	61.9%	157	59.0%
Pilot	65	91.5%	63	73.3%	128	81.5%
Pilot-navigator	0	0.0%	4	4.7%	4	2.5%
Military engineer	6	8.5%	19	22.1%	25	15.9%
Civilian specialists, of which:	56	44.1%	53	38.1%	109	41.0%
Engineer	47	83.9%	34	64.2%	81	74.3%
Physician	6	10.7%	11	20.8%	17	15.6%
Civilian pilot	1	1.8%	1	1.9%	2	1.8%
Economist	1	1.8%	0	0.0%	1	0.9%
Biologist	1	1.8%	1	1.9%	2	1.8%
Journalist	0	0.0%	1	1.9%	1	0.9%
Physicist-Mathematician	0	0.0%	3	5.7%	3	2.8%
Actor	0	0.0%	1	1.9%	1	0.9%
Film/stage director	0	0.0%	1	1.9%	1	0.9%
Total	127	100%	139	100%	266	100%

Table compiled by the authors based on their own data

Note: *n* — cosmonaut number.

selections became open to a wider range of specialists and young people.

A comparative analysis of mortality among cosmonauts with SF experience was performed using internal and external control groups. The "internal" control group was formed from cosmonauts without SF experience, which helped minimize the influence of the "healthy worker" effect due to similar health characteristics [10]. The male population of Russia was taken as the "external" control group. The sources of information on causes of mortality in the male population of Russia in 1960–2023 were the Russian demographic database,[2] Rosstat data,[3] the Demographic Yearbook of Russia,[4] and the Russian Statistical Yearbook.[5]

Due to restrictions on the publication of data on mortality from external causes in the Russian population in effect since 2023, a separate comparative analysis of mortality for this category was not conducted.

The risk of death among cosmonauts was assessed based on the standardized mortality ratio (SMR), calculated using formula (1). The statistical significance of SMR was assessed using a 95% confidence interval (95% CI). Standardization was performed using the indirect method.

$$\mathrm{SMR} = \frac{m^{cosm}}{\Sigma n_i^{cosm} \times R_i^{cont}}, \qquad (1)$$

where m^{cosm} — total number of deceased in the cosmonaut cohort (group);
n_i^{cosm} — number of person-years of observation for the i-th age subgroup in the cosmonaut cohort (group);
$R_i^{cont} = m_i^{cont} / n_i^{cont}$ — estimate of absolute risk for the i-th age subgroup in the control group;
m_i^{cont}, n_i^{cont} — number of deaths and number of person-years of observation for the i-th age subgroup in the control group.

Statistical processing of the data obtained was carried out using the MS and Stata 14 software packages. Using the Shapiro–Wilk test to assess the normality of distribution and Student's t-test, the mean values and their standard errors were calculated. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Structure of causes of death among cosmonauts with and without SF experience

As of the cohort closure date of 31.12.2023, the number of person-years of observation was 9119. Data on the vital status of the cosmonauts are presented in Table 1. The main causes of death for cosmonauts in Groups 1 and 2 are presented in Table 3.

In both cosmonaut groups, diseases of the circulatory system rank first in the structure of known causes of death (Group 1 — 53.3%; Group 2 — 22.9%). Among cosmonauts with SF experience, mortality from malignant neoplasms was recorded in 26.7% of cases, while mortality from external causes accounted for 13.3% of cases. In the group of cosmonauts without SF experience, mortality from external causes accounted for 18.6% of cases and ranked second in the mortality structure. Malignant neoplasms ranked third, being the cause of death in 15.7% of cases.

Our study cannot offer a complete picture of the cosmonaut mortality structure due to the large proportion of

Table 3. Causes of death among cosmonauts with and without SF experience during the observation period of 1960–2023

Causes of death (ICD-10)	Group 1		Group 2		Total	
	n	%	*n*	%	*n*	%
Diseases of the circulatory system (I00–I99)	24	53.3%	16	22.9%	40	34.8%
Malignant neoplasms (C00–C97)	12	26.7%	11	15.7%	23	20.0%
External causes (V01–Y98)	6	13.3%	13	18.6%	19	16.5%
Other causes (not belonging to the specified classes)	3	6.7%	1	1.4%	4	3.5%
Unknown	0	0.0%	29	41.4%	29	25.2%
All causes combined	45	100%	70	100%	115	100%

Table compiled by the authors based on their own data

Note: *n* — cosmonaut number.

[2] Russian Demographic Database of the Center for Demographic Research at the Russian Economic School. URL: http://demogr.nes.ru/
[3] Federal State Statistics Service (Rosstat). URL: https://rosstat.gov.ru/
[4] Demographic Yearbook of Russia 2023: Стат. сб. — Moscow: Rosstat; 2023.
[5] Russian Statistical Yearbook 2024: Stat. collection — Moscow: Rosstat; 2024.

unknown causes of death among cosmonauts from the second group. For 29 individuals (41.4%) selected into the corps but without SF experience, data on the cause of death is lacking due to significant difficulties in tracking life trajectories after the end of their cosmonaut careers. For this reason, the calculation of cause-specific standardized mortality ratios for cosmonauts in Group 2 was not performed.

Mortality of cosmonauts with SF experience compared to the male population of Russia (external control)

Extending the observation period of the cosmonaut cohort from 58 to 63 years led to a narrowing of the confidence interval boundaries for the studied indicators, thus enabling more precise results to be obtained. Table 4 shows the SMR dynamics for death causes among cosmonauts who completed SF, considering all causes and specific disease categories, compared to the male population of Russia.

The mortality risks for cosmonauts from all indicated causes remain lower compared to the male population of the country. A slight increase in the risk of death from malignant neoplasms attracts attention, with the SMR rising from 0.60 (95% CI 0.29–1.12) in 2018 to SMR = 0.62 (95% CI 0.32–1.09). Although being minimal, this increase is of interest due to the narrowing of the 95% CI to a borderline value. The confidence interval is a range that contains the true value of a parameter with a probability of 95% [11]. In cases where the confidence interval includes the value of 1, the differences cannot be considered statistically significant. In earlier studies, the upper limit of the 95% CI for the SMR from malignant neoplasms significantly exceeded 1, evidently not allowing the interpretation of the reduced risk as reliable. In the present study, the upper limit of the 95% CI has narrowed to a value of 1.09, which raises additional questions for researchers.

The trend toward an increased risk of cosmonaut mortality from malignant neoplasms can be explained by several reasons. First, a number of researchers point out that mortality due to malignant neoplasms is less susceptible to the influence of the "healthy worker effect" (HWE) than other natural causes, due to the long latent period of development [12–14]. Moreover, the strength of the HWE itself decreases over time from the onset of employment: the HWE is most significant at a younger age at the beginning of a career. Along with an increase in the length of service and age, the influence of the HWE decreases, and the worker's health status approaches that of the general population to which they belong [15]. Thus, for analyzing cosmonaut mortality from malignant neoplasms, the general population can be used as a comparison group, and the dynamics of this particular indicator will be of great interest in the future.

Second, Reynolds et al. [7] established increased risks for the development of certain types of cancer among astronauts (compared to the general US population), particularly skin melanoma. Although a direct link to astronauts' working conditions was not established, the authors noted increased risks for both standardized incidence ratio (SIR 252; 95% CI 126–452) and mortality (SMR 508; 95% CI 105–1485) specifically due to skin melanoma. However, such results are characteristic of aircraft pilots, who constitute the majority among US astronauts (235 (69.5%) out of 338 individuals) and who are more exposed to ultraviolet radiation than to cosmic radiation. Among the cosmonauts in the studied cohort, the proportion of pilots (military and civilian) was also significant (52.0% among those who completed a SF; 46.0% among those who did not), but no deaths from skin melanoma were recorded in either group.

The aforementioned US study [7] also indicated a higher risk of incidence (but not mortality) among astronauts due to prostate cancer development (SIR 162; 95% CI 109–232), which the authors associate with earlier and more thorough screening that begins at age 40

Table 4. **Standardized mortality ratios for cosmonauts with SF experience, compared to the male population of Russia, by cause of death and observation period**

Causes of death	Observation period, years					
	1960–2018			1960–2023		
	SMR	95% CI		SMR	95% CI	
All causes of death	0.39	0.28	0.54	0.37	0.27	0.50
Malignant neoplasms	0.60	0.29	1.12	0.62	0.32	1.09
Diseases of the circulatory system	0.42	0.26	0.66	0.45	0.29	0.67

Table compiled by the authors based on their own data

Note: SMR — standardized mortality ratio; 95% CI — 95% confidence interval.

for this professional group, compared to age 50 for the general population. In Russia, according to current clinical guidelines,[6] men over 50 are also considered at risk for prostate cancer development, requiring screening diagnostic methods (determination of prostate-specific antigen (PSA) in the blood). PSA testing is included in the annual medical examination program for cosmonauts — members of ISS crews, also starting from age 40, similar to astronauts. It is worth noting that during our study, two cases of death due to prostate cancer were recorded among cosmonauts with SF experience; however, the results seem too premature to discuss causal relationships. In the future, while continuing to monitor the established cosmonaut cohort, it is necessary to maintain oncological vigilance, especially considering the increase in the duration of space stay among deceased cosmonauts.

The total duration of completed SF as of 31.12.2023, was 31,207 days (of which 4048 days (12.9%) were accounted for by now-deceased cosmonauts). The average time spent in SF conditions per career for one living cosmonaut was 331.8 days, while for a now-deceased cosmonaut it was 76.5 days ($p < 0.01$). During the course of the study, differences in causes of death depending on the average duration of SF have not been established, which is an object for future research.

In our study, a comparative analysis of cosmonaut mortality from external causes was not conducted, which is due to the absence of data on mortality from this class of causes in the Russian population. In a previously conducted study [9] covering the period of 1960–2018, the risk of death from external causes for cosmonauts with SF experience was 0.39 (95% CI 0.14–0.85) compared to the male population of Russia. No new cases of cosmonaut death from external causes were registered upon extending the observation period, which eliminates the theoretical possibility of an increased risk.

Mortality of cosmonauts with SF experience compared to cosmonauts without such experience (internal control)

The study of trends in the SMR among cosmonauts with SF experience compared to the internal control — cosmonauts without SF experience — with an increase in observation duration deserves separate attention (Table 5).

Table 5. **Standardized mortality ratios for all causes combined for cosmonauts with SF experience, compared to cosmonauts without SF experience, by observation period**

Observation period, years	SMR	95% CI	
1960–2018	0.66	0.46	0.91
1960–2019	0.70	0.50	0.95
1960–2020	0.68	0.49	0.93
1960–2021	0.68	0.49	0.92
1960–2022	0.71	0.51	0.95
1960–2023	0.73	0.53	0.98

Table compiled by the authors based on their own data

Note: SMR — standardized mortality ratio; 95% CI — 95% confidence interval.

Table 6. **Mean age at death of cosmonauts from natural causes, depending on SF experience and observation period**

Observation period, years	Mean age at death (natural causes), years		Statistical significance level, *p*
	With space flight experience	Without space flight experience	
1960–2018	68.8	63.1	<0.05
1960–2023	71.7	65.8	<0.05

Table compiled by the authors based on their own data

[6] Clinical guidelines "Prostate Cancer"; 2021. URL: https://cr.minzdrav.gov.ru/preview-cr/12_3

A gradual increase in the SMR from all causes is observed for cosmonauts with SF experience compared to cosmonauts without SF experience, although remaining statistically significant across all periods. In 2018, the risk of death for cosmonauts who had completed a SF was significantly lower by 34% (SMR = 0.66; 95% CI 0.46–0.91). The five-year extension of the observation period somewhat smoothed out the difference in the risk of death — to 27% (SMR = 0.73; 95% CI 0.53–0.98). A narrowing of the CI boundaries was also noted, with the upper CI boundary gradually approaching the threshold value (1), beyond which the differences lose statistical significance.

The difference in the mean age at death from natural causes between the two cosmonaut groups also remained significant (Table 6).

With the extension of the cohort observation period, an increase in the mean age at death was recorded in both groups: among cosmonauts with SF experience by 2.9 years (to 71.7 years) and by 2.7 years (to 65.8 years) in the group of cosmonauts without SF experience. It is important to note that the trend toward earlier mortality among cosmonauts who did not complete a SF persisted: their mean age at death was almost six years less compared to cosmonauts who had flown to space ($p < 0.05$). The calculated risk and mean age at death indicate a worse health status of those cosmonauts who were selected into the corps but not into spacecraft crews.

Earlier works present additional examples to illustrate this fact. For instance, a separate study [16] was dedicated to the long-term (maximum 30 years) medical monitoring of 36 cosmonauts who had completed SF and 65 cosmonauts without SF experience. According to the authors, their long-term morbidity was more associated with age-related changes, while functional disorders of the cardiovascular system and hypertensive disease were more frequently recorded among cosmonauts without SF experience. In the study [17], survival functions were calculated for 30-year-old cosmonauts who had completed SF in the 1960s and cosmonauts without SF experience (34 and 59 individuals, respectively). The survival curve for cosmonauts who had not completed a SF showed a clear increase in mortality in the age range of 55–60 years, subsequently falling below the analogous survival curve for cosmonauts with SF experience.

Undoubtedly, the anticipation of being assigned to a prime crew is associated with significant psychoemotional stress, which only intensifies over time in the absence of professional fulfillment. A study based on the analysis of 91 biographies of Russian cosmonauts and 14 biographies of US astronauts established that the anticipation of a SF and the risk of being discharged from the corps are the most negative stress factors affecting cosmonauts' health [18]. A SF itself can be viewed as a source of distress (the negative component of stress), but also as a source of eustress — the positive component of stress that mobilizes the body's protective functions and compensates for the impact of negative SF factors. Cosmonauts who have not completed a SF find themselves in a worse position compared to cosmonauts with SF experience due to the absence of eustress. In the aforementioned study, the average lifespan of non-flying cosmonauts was shorter than that of flying cosmonauts (59.3 and 65.9 years, respectively).

Chronic stress, including that associated with professional activity, negatively affects the body's homeostasis, with its link to morbidity and mortality having been described by many authors [19, 20]. However, the direction of the causal relationship can be interpreted in two ways: prolonged denial of flight clearance can cause a deterioration in health status, and conversely, identified poorer health indicators can be the reason for denial of SF clearance.

Overall, the health of cosmonauts, even those who have not completed a SF, is significantly better compared to the male population of Russia. Thus, the SMR, calculated considering all causes of death for this group over the 63-year observation period, was 0.47 (95% CI 0.37–0.59).

The identified mortality indicators for cosmonauts without SF experience, which are worse compared to cosmonauts who have completed SF, indicate the existence of other factors and individual-level mechanisms affecting their health. In an attempt to search for such

Table 7. Mean age at death of cosmonauts with and without SF experience, by initial education

Initial education	With SF experience, years	Without SF experience, years	Statistical significance level, *p*
Engineers	67.5 ± 16.5	67.9 ± 15.7	0.519
Military specialists	68.1 ± 15.5	60.3 ± 15.3	0.015
Others	65.5 ± 10.2	59.8 ± 12.9	0.249

Table compiled by the authors based on their own data

Note: *p* — level of statistical significance; data are presented as mean value and standard deviation of the mean *M* ± *SD*.

factors, we carried out an analysis of the mean age at death of cosmonauts depending on their initial education (Table 7). It is important to note that the mean age of enrollment in the cosmonaut corps showed no differences based on either education or SF experience, ranging 30.0–33.3 years for all cosmonauts.

In the structure of initial education, the overwhelming majority of cosmonauts were military specialists (55.9% in Group 1 and 61.9% in Group 2), while civilian engineers ranked the second (37.0% and 24.5%, respectively) (Table 2). When assessing the mean age at death of engineers and cosmonauts with other education in both groups, no statistically significant differences were established. However, a significant difference in the mean age at death was shown for military specialists: for cosmonauts who graduated from military educational institutions and did not complete a SF, the mean age at death was 60.3 years, which is eight years less compared to cosmonauts with the same education but with SF experience (68.1 years, $p = 0.015$).

Furthermore, when the analysis was limited to data on military pilots, who constitute the majority among military specialists (91.5% in Group 1; 73.3% in Group 2), the differences became even more substantial: the mean age at death for pilots with SF experience was 67.7 years, compared to 56.7 years ($p = 0.006$) for those without SF experience. No statistically significant differences in the mean age at death were obtained for military engineers. This observation might be explained by the methods and pathways for realizing professional potential, which differ significantly for civilian and military specialists [21]. For engineers, the unique experience gained during the recruitment process and time spent in the cosmonaut corps is a valuable symbolic capital, actively exploited later when changing their field of activity. For military specialists, unlike civilian ones, career strategy is aimed at achieving specific objectives, and a SF itself is an important goal on this path.

The training conditions for military and civilian specialists also differed: cosmonauts with a civilian profession were not required to be permanently stationed at the Gagarin Cosmonaut Training Center. In the absence of prospects for a SF, they could return to their primary jobs, which was impossible for cosmonauts whose military profession limited their professional mobility.

Regarding pilots, it is necessary to remember that people in this group (especially pilots of high-maneuverability aircrafts) should possess certain personality characteristics prior to selecting this profession [22]. This was convincingly demonstrated earlier in fundamental and applied experimental psychological studies [23]. Therefore, the personality type of a pilot is also a determining factor in the established pattern.

The group of cosmonauts selected into the corps but not cleared for SF deserves closer attention and thorough study of their health status, including mortality, for a number of reasons. On the one hand, the very fact of successfully passing the professional selection process into the cosmonaut corps already confirms the high qualifications and good health status of this group of individuals, who face additional negative factors throughout their careers and while awaiting flight assignment. This necessitates the development of measures to prevent early mortality, including personalized medical and psychological assistance. On the other hand, comprehensive data on the health of cosmonauts who were selected but did not complete a SF is key to establishing the true long-term effects of spaceflights on the human body, since this professional group can serve as a unique “internal” control in analytical epidemiological studies of the health of cosmonauts who have completed SF. To date, among cosmonauts without SF experience, the proportion of individuals with unknown causes of death remains significant at 41.4% (Table 3), which prevents a comparative analysis of mortality by specific causes.

CONCLUSION

Regular five-year extensions of the observation period for the historical cohort of Soviet and Russian cosmonauts have established that the risk of death for cosmonauts with SF experience remains undeniably lower compared to the male population of Russia. However, a general oncological vigilance in this group continues to exist, confirmed both by the lack of reliability in the reduced risk of death from malignant neoplasms and by the results obtained by US researchers. Currently, the time spent in space by deceased cosmonauts over their careers remains relatively small compared to the total duration of completed SF, which prevents straightforward conclusions about the connection between cosmonauts' working conditions and such a long-term health indicator as mortality. Based on the observed changes in the calculated values obtained under a longer observation period, it can be unequivocally stated that further research in this area is necessary. Future directions should focus on the long-term consequences of the entire set of factors affecting cosmonauts both on Earth (e.g., medical radiation examinations) and in space (in particular, the duration of extravehicular activity). Solving these tasks is only possible by extending the observation period of the established cohort with regular updates of the calculated data.

Cosmonauts who have not completed a SF also possess better health compared to the general population. However, in this group, the role of other, individual-level factors reflected in mortality has been demonstrated. Thus, the established connection between initial education and the mean age at death indicates the necessity for in-depth monitoring of the health status of this cosmonaut group after leaving the corps. This information can serve as the basis for developing therapeutic and preventive measures, including timely psychological support based on an individual, personalized approach. Furthermore, elucidation of the causes of death among cosmonauts without SF experience can contribute to revealing other mechanisms affecting their health.

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