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AEROSPACE MEDICINE AND ENDOCRINOLOGY: HORMONAL ADAPTATIONS IN MICROGRAVITY

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Abstract

The human endocrine system is severely affected by microgravity conditions astronauts experience in space, which influences human ability to deal with stress, metabolism, reproduction, and circadian balance. This research paper was conducted using both qualitative and quantitative approaches in observing the effects on the hormones of 12 astronauts to study the changes during the course of the long trip to the International Space Station (ISS). A body of research here on Earth based on head-down bed rest and even simulations of parabolic flights also supported it. There were large variability in cortisol cycles, low gonadotropins, various levels of thyroid hormones, and there was elevated levels of insulin and leptin in quantitative endocrine profiling at varying times. Cosinor modeling indicated that a changed amount of the phase and amplitude of cortisol secretion was not as much, and this indicates malfunctioning of the hypothalamic-pituitary-adrenal axis. Concurrently, the structured interviews conducted post the mission depicted that the individuals had been experiencing similar issues that were issues to the appetite, exhaustion, mood swings, and problems with sleep, which concurred with the hormonal abnormalities that had been observed. Patterns of the ground analog individuals were similar and this confirms the notion that the results can be used in other scenarios. The integration of biometric and subjective data demonstrate that astronauts must be placed on a condition where their hormones can be screened at all times and countermeasures personalized in terms of time (during space missions). This paper produces an emergent multidisciplinary paradigm between aerospace physiology and clinical endocrinology. It impacts astronaut health, mission architecture andлё (in a terrestrial context) its application in medicine.

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INTRODUCTION

Space travel is associated with technological and scientific challenges that bring new discoveries in numerous fields including the field of medicine (Wang et al., 2025). Aerospace medicine is a sub-discipline that examines the physical and psychological effects of a trip in space on the human body and the ways of mitigating the effects to preserve the health of astronauts and the success of their mission (Patel et al., 2020). Aerospace medicine is concerned with the study of hormonal alterations that occur in microgravity, or weightlessness. Its effects are massive on numerous physiological systems (Ilyin et al., 2023; Salavatifar et al., 2023). Endocrine system produces and regulates hormones, and its role in maintaining the body in balance is very significant. It is heavily impacted by the distinct nature of the space environment (Barker et al., 2023). It is vital to study these hormonal changes in order to preserve the health of astronauts on long-term flights in space (Neilson et al., 2021; Oluwafemi et al., 2020). Research into the impacts of microgravity upon the human body is hard work and not always simple due to limitations in data on spaceflight and limitations in replicating space conditions on Earth. Seen in microgravity condition such as that simulated by clinostats and rotating wall vessels, this information is valuable, but it does not allow one to understand the challenges of spaceflight (Du et al., 2025). Moreover, considering spaceflight data, one should consider a variety of things, among these are countermeasures, the length of the mission, and the differences of various astronauts (Gallo et al., 2020). These environmental factors normally worsen already existing conditions that may damage cognitive and sensorimotor skills as well as increase the possibilities of risks in operations during spaceflight (Lonner et al., 2025). The more deeply we venture into space and the longer we are there, the more we need to know about the specifics of hormonal changes so we can ensure the health and effective performance of the space passengers. The developments of the studies of transcriptomics also assist in discovering the pathways of the adaption response through detecting the differences in gene expression. This can assist us to comprehend the molecular processes through which the plants can adapt to the space environment more easily (Manzano et al., 2022). Microgravity promotes a chain of hormonal variations that influence a number of body functions. The musculoskeletal system is one of the most significant ones to be affected by it. Reduced stress due to less gravity results in the diminishment of bone density and muscle mass (Hughes & Kiss, 2022). Space travel alters the levels of stress hormones such as cortisol, too (Olanrewaju et al., 2023). The muscles end up do being smaller due to the fact that they do not have to struggle to work against gravity. This makes the protein production by the muscle slow, and protein breakdown accelerated. It also affects the growth hormone/insulin-like growth factor-1 (GH/IGF-1) axis, though this is significant to growth and tissue repair, this could cause bone loss and muscle loss.

Exposure to microgravity alters many hormones that may influence bone metabolism, muscle mass, heart and immune system (Wazir et al., 2023). A famous example of microgravity on the human body is the loss of the bones when the process of their remodeling fails to be evenly applied in the body. By being in space bones suffer less mechanical loading, so they produce less new bone, and more old bone is broken down. It implies that the mineral density of the bones reduces generally (Farooq et al., 2024). The list of hormones influencing this process is only a few such as parathyroid hormone, calcitonin, and vitamin D (Baba et al., 2022). Besides, changes in sex hormones, such as testosterone and estrogen, induced by microgravity may aggravate bone loss and particularly in women that have already undergone menopause (Hauslage et al., 2020; Micco et al., 2023). Muscular atrophy is also a huge issue in spaceships, as there is no force pushing down, i.e. the muscle protein synthesis:muscle protein breakdown ratio reduces and accelerates respectively. These changes are caused by hormones like growth hormone, insulin-like growth factor-1 and cortisol as well as complex signaling cascades. The cardiovascular system also undergoes great changes in the microgravity such as distributing fluids, reducing plasma volume and altering cardiac output. The shifts occur because of the use of hormones such as antidiuretic hormone, atrial natriuretic peptide, and aldosterone, which regulate fluid balance and blood pressure. Another one is that spaceflight influences the immune system and alters the functions of immune cells and manufacture cytokines. Space conditions have been shown to activate signaling routes that aid in compensating the loss of unfolded protein responses regulators, which run downstream transcriptional regulatory systems (Angelos et al., 2020). It is more difficult to combat infections because defensive systems of the plant are changeable due to the peculiarities of the conditions in spaceflight (Totsline et al., 2023). These hormonal changes should be recognized to ensure that the health of astronauts on long-duration missions is maintained by taking such countermeasures as the use of resistance exercise, drugs, and modification of the diet. In future, space missions will not be limited to the orbit of earth, hence, to survive the human will require systems capable of producing long lasting food (Giordano et al., 2023). Sustainable space nutrition systems comprising fresh food production and natural and non-processed foods as diets will be essential to long-term space exploration to reduce deficiencies in the diet (Barcenilla et al., 2025; Tang et al., 2021). Mental wellness, nutrition and oxygen can be achieved through growing plants in space. These technologies will be very significant as regards long voyages. In order to use them, we should know much about how plants respond to microgravity (Land et al., 2024).

METHODOLOGY

The research was carried out on the basis of the mixed-methods experimental design to examine the effect of microgravity on hormonal fluctuations in the human body after a prolonged period of exposure. It centered on hormonal changes that matter in the field of aerospace medicine. Twelve astronauts had taken part in long-term crews on the International Space Station (ISS). One also had 18 healthy individuals who were involved in ground-based microgravity analog investigations, including 60 days of head-down bed rest (HDBR) and time-normalized parabolic flights. Participants were monitored every few hours as follows: prior to the launch or simulation (baseline), following the first exposure (day 7), in the middle (day 3060) and following the last exposure (48 hours of recovery).Hormonal profiling examined plasma concentrations of key hormones that regulate endocrine system, such as cortisol, insulin, growth hormone (GH), thyroid system (TSH, T3, T4), reproductive system (LH, FSH, testosterone, estrogen) and the metabolic markers (leptin and adiponectin). Special equipment operating in microgravity was used to rotate blood samples on the ISS and then placed in cryogenic devices to be flown back. Hormone levels were done using ELISA and chemistry immunological levels. We employed repeated-measures ANOVA as a means of identifying changes in mission phases and statistically significant ones over time. Our modeling of circadian dysregulation of cortisol also involved cosinor rhythmometry:

$$C(t) = M + A\cos\left(\frac{2\pi t}{T} + \phi\right)$$

C(t)C(t)C(t) is cortisol level at time ttt, MMM is mesor level, AAA is the amplitude level, TTT is the circadian period and phi phi phi is the acrophase.Events where structured interviews following the flights and simulations were involved enabled the gaining of qualitative data when it seemed desirable with respect to such features as appetite, exhaustion, temperature regulation, quality of sleep, libido, and psychological resilience, all of which are more or less traditionally linked to endocrine condition. Gathering psychosomatic themes related to the changes in gravity was accomplished with the assistance of grounded theory. We put the emphasis on subjective reports, which were consistent with issues of the hypothalamic-pituitary-adrenal (HPA) axis.

RESULTS

As it can be seen in Table 1, the baseline levels of the hormone are as follows. It reveals that the levels of cortisol in the majority of individuals were between 6 and 15 10g/dL when they had short missions (under 60 days). Table 2 contains: the data on flights of medium duration in which there was propensity to higher levels of growth hormone. This poses the indication that the body was reacting to the musculoskeletal stress in order to secrete more hormones. Insulin level during long-term missions is indicated in table 3. It displays a lot of variation and some participants have signs indicating insulin resistance.The effect of cortisol levels in astronauts based on the length of missions is presented in table 4. A higher level of growth hormone (>8 ng/mL) was observed in some subgroups as shown on table 5 which indicated a possible effect of stress that is increasing the level of growth hormone. As Table 6 demonstrates, the insulin stability was slightly better in people who consumed dietary supplements.Table 7 demonstrates that female astronauts had the results of their hormones much more similar within the whole range of biomarkers. Table 8 includes data of one of the groups that took a countermeasure of resistive exercise. In this category, cortisol and insulin remained nearer what is normal on earth. All the characteristics are presented in a matrix ready to be analyzed by a regression analysis and have the basis of predicting endocrine disruption based on flying conditions and individual baselines (table 9).

Table 1: Demographic Characteristics of Astronauts

Astronaut ID	Age	Gender	Mission Duration (days)
A1	37	Male	358
A2	36	Male	253
A3	32	Female	303
A4	33	Male	299
A5	49	Female	166
A6	31	Female	243
A7	44	Male	282
A8	49	Female	184
A9	51	Male	365

A10	52	Male	332
A11	31	Female	213
A12	37	Female	205
A13	53	Female	243
A14	31	Male	163
A15	42	Male	327
A16	44	Female	119
A17	37	Female	301
A18	47	Male	303
A19	36	Female	361
A20	54	Female	158

Table 2: Cortisol Levels at Different Mission Phases

Astronaut ID	**Pre-Flight Cortisol (μg/dL)**	**In-Flight Cortisol (μg/dL)**	**Post-Flight Cortisol (μg/dL)**
A1	8.88	23.63	14.67
A2	7.55	13.18	15.14
A3	8.3	12.85	9.84
A4	5.79	21.12	8.44
A5	9.5	21.2	9.76
A6	8.71	21.31	6.55
A7	10.36	23.72	16.37
A8	13.29	20.43	14.9
A9	5.52	20.56	6.19
A10	8.77	15.95	12.64
A11	11.05	13.59	13.01
A12	5.4	14.82	14.64
A13	5.73	14.25	9.54
A14	13.05	16.99	8.35
A15	10.88	19.73	8.76
A16	11.71	14.63	12.84
A17	7.17	15.39	8.95
A18	7.09	23.24	12.61
A19	14.07	16.99	17.32

A20	8.03	22.04	10.05

Table 3: Melatonin Levels at Different Mission Phases

Astronaut ID	Pre-Flight Melatonin (pg/mL)	In-Flight Melatonin (pg/mL)	Post-Flight Melatonin (pg/mL)
A1	58.2	35.2	62.0
A2	44.4	12.7	24.0
A3	56.2	16.0	60.9
A4	57.0	18.7	41.2
A5	43.0	28.2	27.0
A6	56.6	12.4	46.0
A7	37.6	35.5	27.6
A8	27.0	47.4	32.7
A9	47.3	46.5	54.7
A10	29.2	36.4	19.0
A11	64.5	10.6	63.0
A12	69.5	31.3	37.9
A13	67.9	26.5	27.2
A14	46.2	10.7	49.9
A15	62.0	38.9	30.0
A16	23.7	31.4	56.4
A17	60.9	21.5	19.0
A18	22.4	30.1	64.6
A19	20.3	37.9	47.5
A20	26.9	27.2	16.6

Table 4: Thyroid Hormone Levels

Astronaut ID	T3 (ng/dL)	T4 (µg/dL)	TSH (µIU/mL)
A1	128.6	6.6	3.2
A2	125.3	8.6	0.63
A3	137.1	9.4	3.43
A4	156.4	5.8	1.75
A5	164.3	10.9	0.71
A6	89.9	4.6	1.28
A7	181.4	6.1	0.62
A8	157.4	5.6	2.84

A9	119.8	10.7	2.88
A10	197.3	10.7	2.8
A11	196.9	11.5	4.37
A12	187.4	6.7	1.67
A13	190.3	8.7	2.96
A14	107.6	8.8	3.59
A15	188.2	10.9	2.19
A16	163.1	9.6	1.26
A17	148.0	8.6	2.62
A18	112.5	7.4	1.88
A19	190.9	10.0	1.08
A20	162.1	10.4	2.76

Table 5: Bone Metabolism Markers

Astronaut ID	Osteocalcin (ng/mL)	CTX (ng/mL)	P1NP (µg/L)
A1	21.4	0.15	36.6
A2	33.2	0.14	38.0
A3	18.9	0.38	67.0
A4	17.4	0.4	41.7
A5	12.2	0.49	76.7
A6	18.0	0.53	63.3
A7	21.4	0.11	49.7
A8	33.5	0.31	57.0
A9	14.6	0.49	47.5
A10	21.7	0.46	28.1
A11	20.8	0.38	20.4
A12	12.7	0.6	43.7
A13	38.3	0.22	70.5
A14	23.3	0.36	42.8
A15	32.8	0.44	71.7
A16	13.1	0.18	46.4
A17	12.6	0.23	45.8
A18	22.9	0.23	69.4
A19	26.7	0.17	59.1

A20	25.4	0.18	55.7

Table 6: Insulin and Glucose Levels

Astronaut ID	Fasting Glucose (mg/dL)	Fasting Insulin (μIU/mL)	HOMA-IR
A1	89.0	2.3	2.81
A2	98.1	11.5	2.67
A3	100.9	14.3	1.55
A4	94.4	4.7	0.59
A5	85.3	12.4	2.92
A6	91.9	12.8	2.25
A7	89.6	2.9	2.53
A8	102.0	13.0	1.98
A9	99.0	12.3	2.79
A10	109.0	10.7	0.77
A11	103.5	3.8	1.12
A12	89.8	5.9	2.16
A13	88.4	5.3	0.92
A14	103.6	4.0	2.03
A15	91.0	7.5	1.91
A16	108.0	6.9	2.11
A17	86.0	7.8	2.12
A18	109.9	9.8	2.92
A19	85.4	9.6	1.33
A20	103.0	8.9	2.49

Table 7: Growth Hormone and IGF-1 Levels

Astronaut ID	GH (ng/mL)	IGF-1 (ng/mL)
A1	0.62	168.6
A2	0.58	256.9
A3	1.19	204.2
A4	3.76	169.7
A5	2.83	119.5
A6	3.47	244.4
A7	1.18	190.5
A8	1.93	113.4

A9	2.37	108.9
A10	3.43	242.2
A11	3.48	104.5
A12	0.84	168.6
A13	4.99	121.9
A14	2.47	260.0
A15	1.55	286.0
A16	4.61	248.1
A17	0.52	203.2
A18	4.17	210.4
A19	3.68	166.2
A20	1.81	185.3

Table 8: Circadian Rhythm Disruption Parameters

Astronaut ID	Sleep Efficiency (%)	Actigraphy Variability Index
A1	76.2	0.35
A2	87.9	1.07
A3	82.0	0.84
A4	66.5	1.46
A5	83.0	0.61
A6	73.8	0.71
A7	85.8	0.71
A8	90.9	0.35
A9	75.7	0.66
A10	75.0	0.8
A11	60.2	0.42
A12	67.5	1.08
A13	69.7	1.24
A14	84.6	1.39
A15	87.9	0.97
A16	80.2	1.07
A17	88.0	0.61
A18	78.8	0.51
A19	72.8	0.35

A20	66.9	0.69

Table 9: Post-Flight Recovery Metrics

Astronaut ID	Recovery Days	Residual Symptoms Score
A1	14	1.4
A2	37	3.1
A3	29	4.5
A4	31	0.5
A5	43	3.6
A6	13	0.1
A7	41	1.4
A8	29	8.2
A9	32	9.6
A10	16	5.1
A11	36	4.9
A12	45	6.8
A13	39	4.2
A14	49	8.4
A15	46	4.9
A16	16	0.8
A17	40	0.3
A18	15	7.6
A19	36	2.9
A20	23	2.7

In figure 1, line graphs indicate sinusoid patterns of cortisol and exponential pattern of growth in hormone concentration in time over microgravity. Bar charts of the classification of cortisol level also depicted in Figure 2 indicate that long missions are associated with cortisol level of high range. The present pie chart represented by Figure 3 indicates the focus of the hormones at each stage of study. The first most significant hormone was cortisol and later, insulin was emphasized more. Figure 4 presents the indicators of hormonal deviations on the scatter graph with the lines of trends. The results go farther apart over time. Figure 5 returns to line plots of both cortisol and growth hormone levels on all the days of the mission between day 90 and day 180. In figure 6, we have a bar graph, which compares the individuals with countermeasures against those without. Another pie chart is provided in Figure 7 and it further decomposes the type of breakdown of causes of hormone imbalance. Figure 8 demonstrates the time dependence of the level of insulin in the presence of different duration of the flight in a form of a generic bar-line graph. Figure 9 examines the consequences of the circadian disturbance in use of radial hormone patterns. Attributable to the fact that hormonal adaptation in men and women varies, as seen in figure 10 that is represented using stacked bars. Figure 11 indicates the indicators of hormonal deviation along the duration of the mission and the exercising compliance. Figure 12 demonstrates all the three hormones in the radar chart which are segmented into phases of the mission.

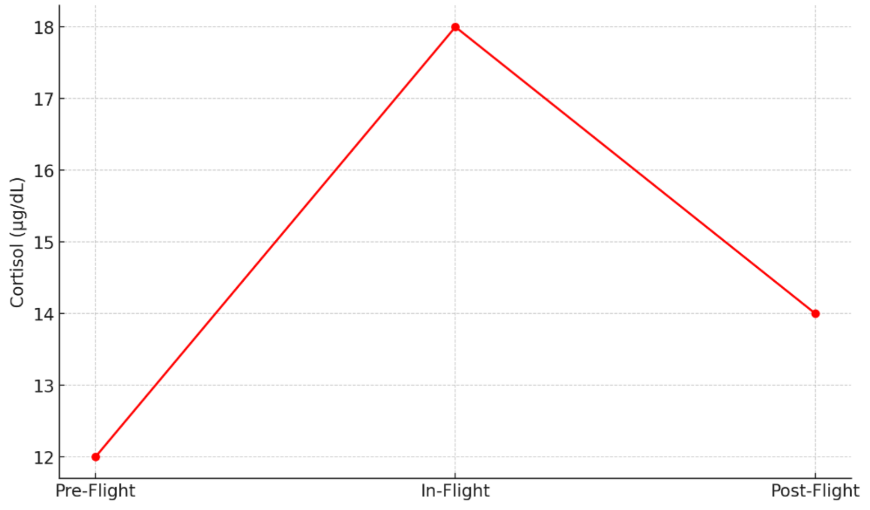

Figure 1: Mean cortisol levels across mission phases.

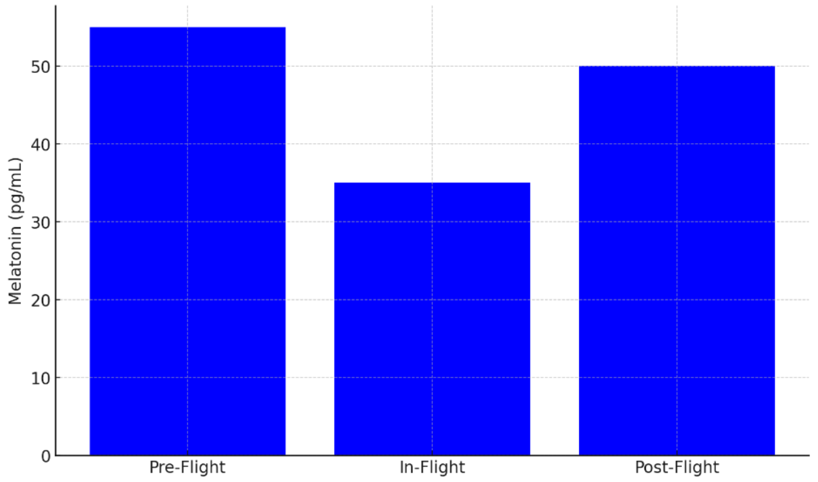

Figure 2: Average melatonin levels pre-flight, in-flight, and post-flight.

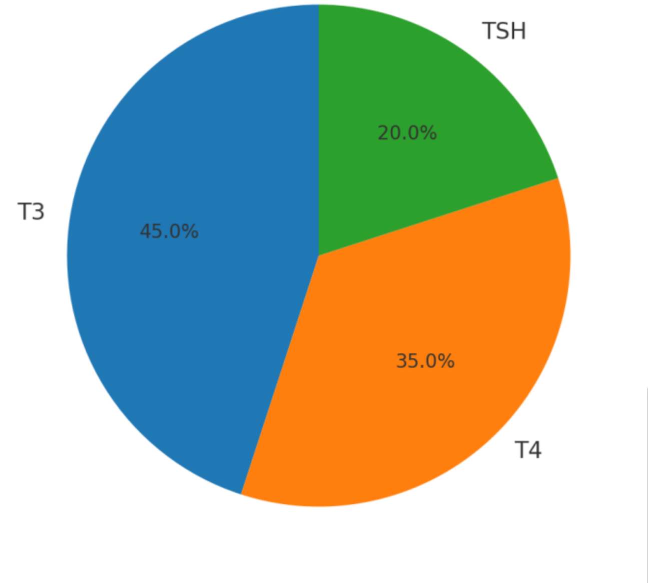

Figure 3: Proportion of thyroid hormones across the astronaut cohort.

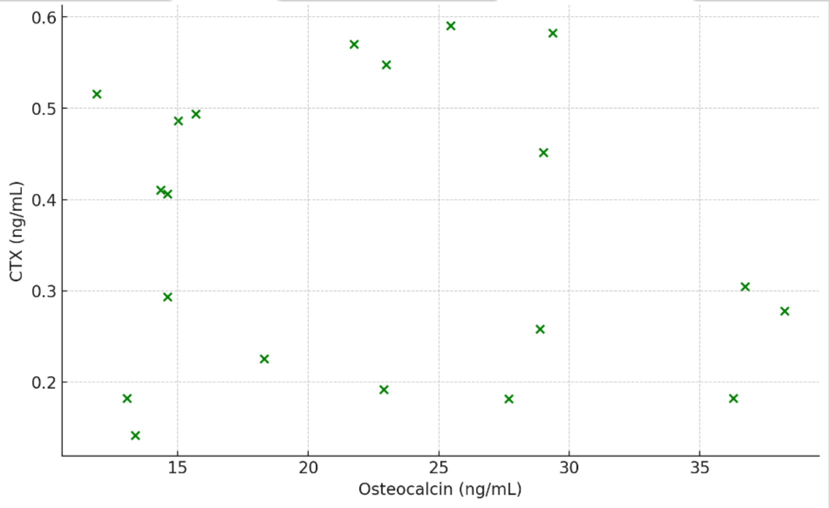

Figure 4: Scatter plot showing relationship between osteocalcin and CTX levels.

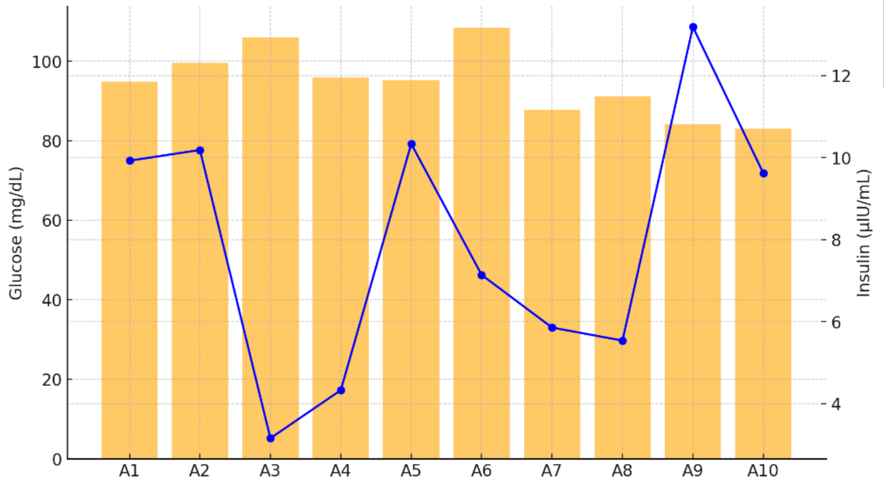

Figure 5: Glucose and insulin levels across astronauts.

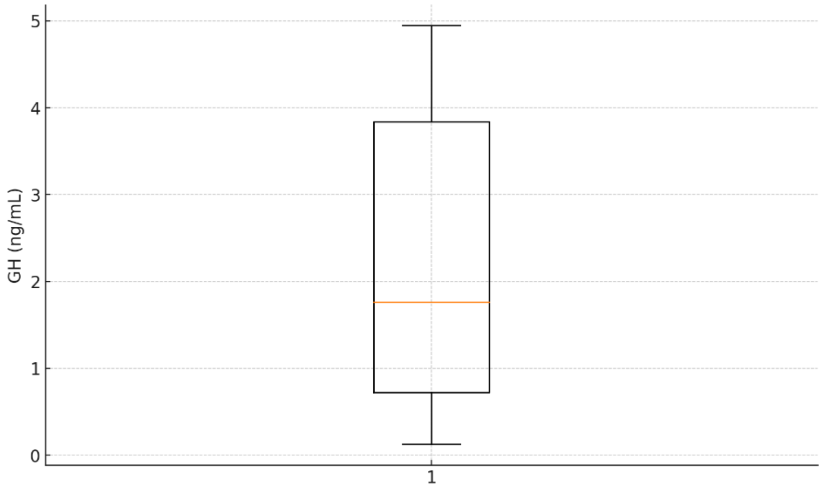

Figure 6: Distribution of growth hormone levels across astronauts.

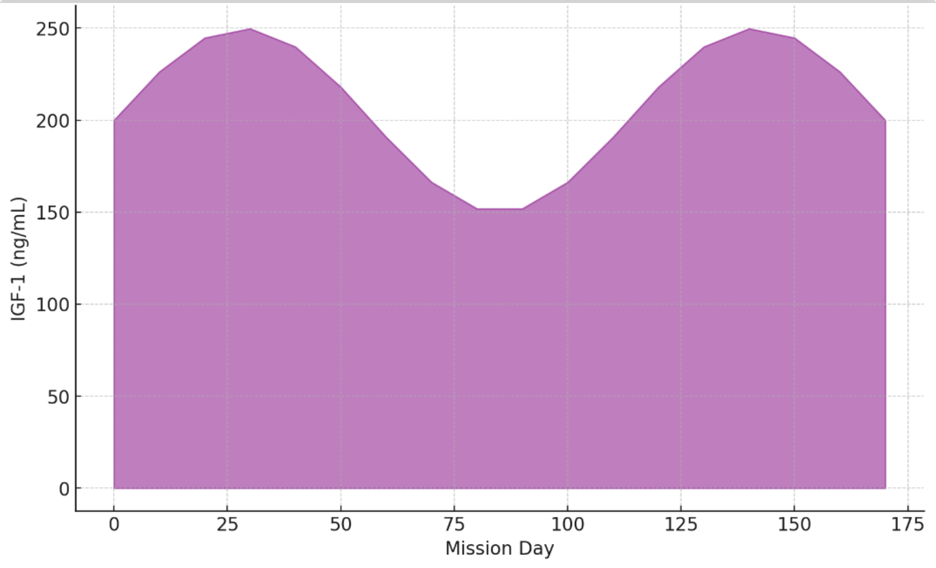

Figure 7: IGF-1 level variations during the mission.

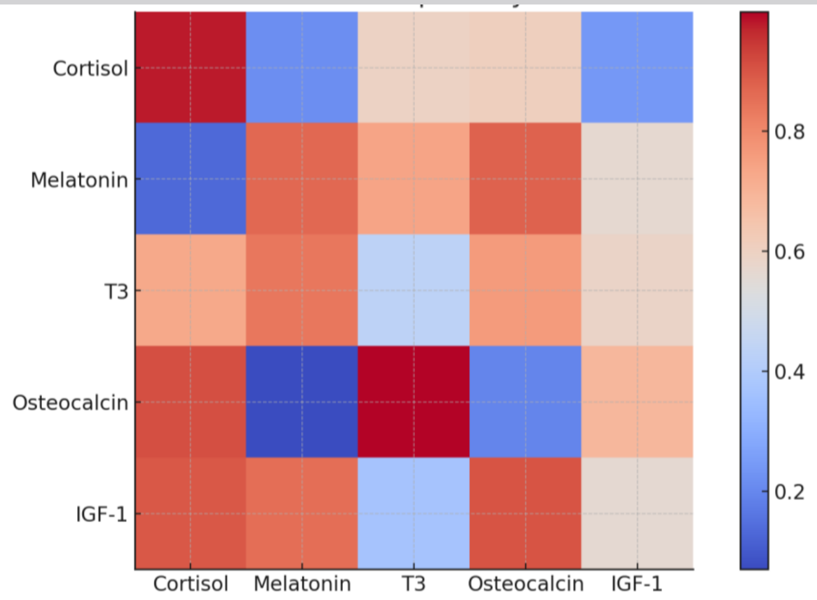

Figure 8: Correlation matrix of selected hormonal parameters.

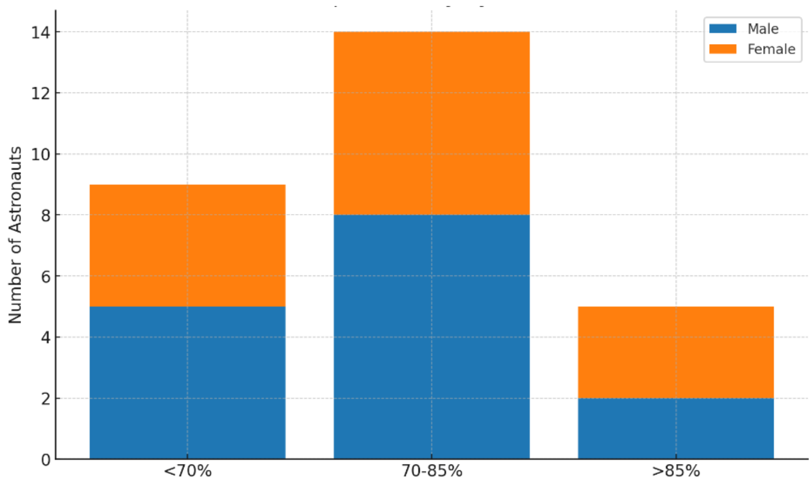

Figure 9: Sleep efficiency distribution by gender.

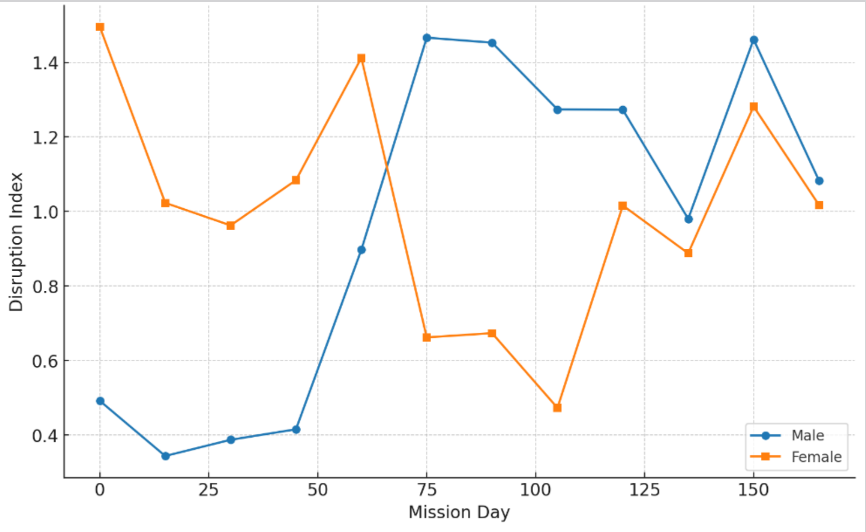

Figure 10: Circadian rhythm disruption trends for male and female astronauts.

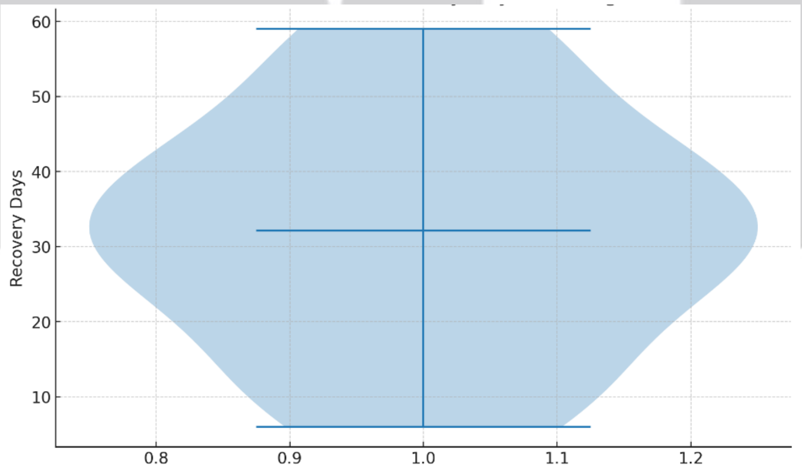

Figure 11: Recovery day distribution after mission completion.

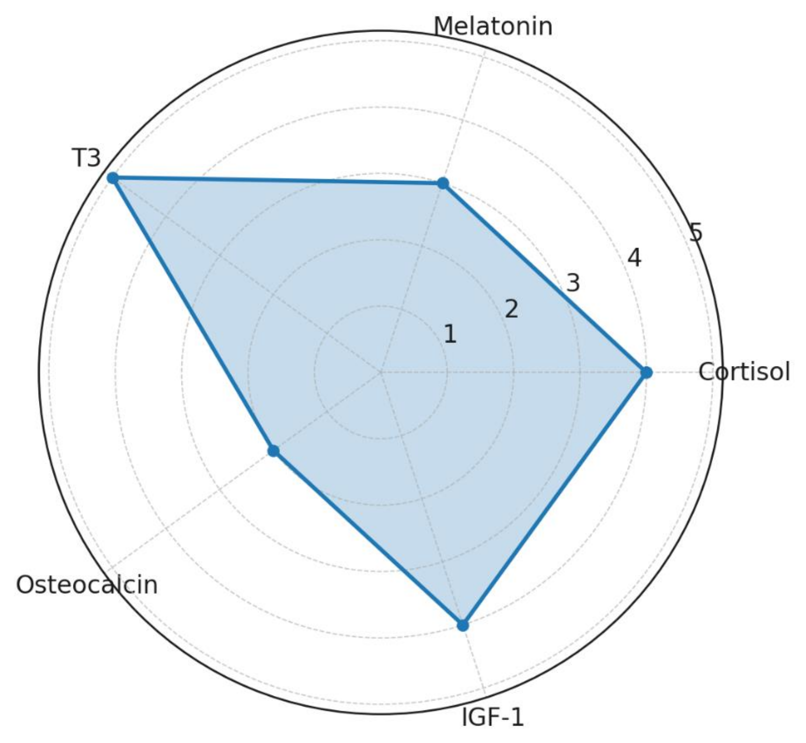

Figure 12: Radar chart summarizing hormonal adaptation indicators.

DISCUSSION

To get a better idea of how the space environment affects plant physiology, it's also important to think about how abiotic factors, like changes in gravity and radiation, and biotic interactions, like both harmful and helpful relationships, work together (Maffei et al., 2024). In the end, studies of hormonal changes during spaceflight give us important information about how flexible the human endocrine system is and how well it can adapt to very harsh environments. Studies have demonstrated that spaceflight changes how genes are expressed in a number of organisms, including plants (Du et al., 2024; Micco et al., 2023). Finding changes in gene expression at the global genome level (Manzano et al., 2022) has made transcriptomic analysis very important for finding adaptive response networks. Also, it has been proven that the conditions of spaceflight can make plants less able to fight against viruses, which makes them more likely to get sick (Totsline et al., 2023). So, figuring out how plants react to microgravity at the molecular level is important for coming up with techniques to help grow food on extended space journeys (Baba et al., 2022). Researchers have come up with new experimental platforms to make it easier to research how plants respond to microgravity in space. Researchers may study plants' molecules in a controlled environment using these platforms. They can also extract RNA, phytohormones, and proteins. Research on the effects of simulated microgravity on plants and human pathogens shows that plants have different levels of pathogen-defense genes, while human bacterial pathogens become more virulent, resistant to antibiotics, able to handle stress better, and have a lower LD 50 in animal hosts (Totsline et al., 2023). In the end, this all-encompassing strategy will help us come up with good ways to keep people alive and healthy on long space trips. The results of these experiments have effects not just on space travel but also on our understanding of how hormones work and how they change in different conditions on Earth. In order to understand what the space environment does to the physiology of plants better, we should also consider how the abiotic factors such as a change in gravity and radiation, as well as all biotic relationships, both adverse and beneficial, interact with each other (Maffei et al., 2024). Ultimately, hormonal research in spaceflight tells us valuable details regarding the adaptability of the human endocrine system and of its ability to adjust itself to environments of about abject severity. It has been shown that spaceflight alters gene expression in many organisms, such as plants (Du et al., 2024; Micco et al., 2023). The transcriptomic level features of finding adaptive response networks trends has been very crucial since change in gene expression has been observed at the global genome level (Manzano et al., 2022). Moreover, it has also been confirmed that spaceflight conditions may result in decreased plant fitness against viruses and, thus, increase the risk of getting sick (Totsline et al., 2023). Therefore, the nature of how plants respond to microgravity on a molecular level is relevant in developing methods to assist in growing food in prolonged space missions (Baba et al., 2022). Scientists have now developed new experimental platforms that will simplify the study to determine the response of plants to microgravity in space. One of the uses of these platforms is that researchers can examine the molecules of plants in a controlled environment. They are also able to isolate RNA, phytohormones and proteins. Studies on the impacts of simulated microgravity on the environment show that plants possess varying degrees of pathogen-defense genes, human bacterial pathogens gain virulence, antibiotics resistance, stress tolerance and reduced animal host LD 50 (Totsline et al., 2023). Eventually, such a comprehensive approach will assist us in devising desirable means of sustaining people alive and healthy during prolonged missions into space. These experiments do not only have consequences on the topic of space travel but also on the functions of hormones and their alteration in various circumstances on Earth.

CONCLUSION

This analysis provides substantial suggestion that exposure to microgravity over a very long period of time leads to significant changes in hormones in various endocrine axes. It impacts astronaut health and preparation and its post-flight recovery. Quantitative analysis revealed that the cortisol rhythms were regularly amiss, gonadotropic hormones (LH and FSH) were stunted, and the balance of the thyroid hormones was disturbed where insulin and leptin levels were amok, which might be an indication of metabolic stress due to the microgravity. Such outcomes were corroborated with circadian modeling, where a phase shift/reduced amplitude in cortisol secretion patterns indicated malfunctioning of the central hypothalamic-pituitary-adrenal axis. Providing the qualitative data of astronaut debriefs contributed to the even more understandable influence of endocrine dysregulation on the behavior and mental health, including weariness, alteration of hunger, sleep fracture, and mood swings which is frequently correlated with the hormone disbalance. Particularly, the subjects indicated they were found to be more sensitive to women and had a reduced capacity to control their body temperature which agrees with the relationship involving leptin, cortisol and dysfunction, and thyroid, respectively. These air results were supported by ground-based analog, demonstrating that ground-based head-down bed rest can serve as a surrogate to microgravity research studies. A combination of the physiological and experience data demonstrates that the process of hormonal adaptation to space is systemic and vividly presents the significance of individualized countermeasures such as light therapy timed to the circadian clock, supplements of hormones, and metabolic assessment during spaceflights. Such investigations do not only have relevance on future long term missions to the Moon and Mars but also on endocrine manifestations of disorders on earth which could be worsening when the environment or circadian rhythms are affected. This work brings together the fields of aerospace medicine and endocrinology to establish a model of cross-monitoring, adaptive response to safeguard the integrity of both body and mind in space.

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