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Short Communication

Post-flight rehabilitation of an astronaut after long duration mission in space: Through the eyes of a flight surgeon

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ABSTRACT

Dwelling in the microgravity environment of space results in various physiological adaptations, namely, cardiovascular deconditioning, neurovestibular changes, loss of bone, and muscle mass. These changes affect the physiological functioning of the human body on return to Earth. Hence, post-flight reconditioning programs are implemented by the International Space Agencies with the aim of returning the Astronauts to their pre-flight physical condition. This paper deals with the post-flight rehabilitation of an Astronaut, which was conducted by a foreign Astronaut Training Center, after his long duration mission of 6 months on board International Space Station. The rehabilitation program consisted of Post-flight Medical Evaluation and Post-flight Physical Reconditioning. With the advent of the Human Spaceflight Program, the lessons learned in this rehabilitation program would be helpful in formulating post-flight rehabilitation protocol for Indian Astronauts during India's maiden Human Spaceflight mission as well as serve as a template for future exploration missions.

Keywords: Spaceflight, Astronaut reconditioning, Rehabilitation, Flight surgeon

INTRODUCTION

The first human space flight was performed by Yuri Gagarin on board Vostok-1, wherein he completed an orbit around the Earth in approximately 108 min on April 12, 1961.[1] Fast forward to 2024, astronauts have spent close to a year on board the International Space Station (ISS) as a part of their long duration missions (LDMs). Prolonged exposure to microgravity (μG) has diverse physiological effects as the human body adapts to an alien environment. These include reduction in aerobic capacity, loss of bone and muscle mass, reduction of muscle strength, alteration in proprioception and posture, cephalic fluid shift, and consequent cardiovascular changes.[1-6] However, the status of the crewmember is not considered as "sick" but an "adapted" one, which might adversely affect the performance capability on their subsequent return to terra firma.

To counteract the effects of μG, an inflight exercise program is implemented at ISS with the aim of adequately preparing the crew for return to Earth on completion of their LDMs.[7,8] These exercises include treadmill exercise (on the treadmill with a vibration isolation system i.e. TVIS and the 2nd generation treadmill, i.e., T2), cycle ergometry (on cycle ergometer with vibration isolation system i.e. CEVIS and velo-ergometer), and resistive exercise training (on interim and advanced resistive exercise devices i.e. iRED and ARED).[8-10] Despite adhering to the inflight

exercise program, deconditioning could not be prevented completely. Thus, crew members have to undergo a post-flight reconditioning program, which commences 1 day after their return (R+1) from LDMs. The reconditioning program aims to prevent long-term health problems/injuries and to restore their physical condition to pre-flight levels.[11] The paper deals with the post-flight rehabilitation of an Astronaut, which was conducted by a foreign Astronaut Training Center after his mission of 6 months duration on-board ISS.

SCHEDULE

The rehabilitation program consisted of two major activities – Post-flight Medical Evaluation and Post-flight Physical Rehabilitation.

POST-FLIGHT MEDICAL EVALUATION

The crew member underwent the following investigations/assessments:-

(i) Laboratory investigations. Laboratory investigations were carried out as per NASA MEDB guidelines.[12]
(ii) Physical examination by a flight surgeon. It included general and systemic examinations both at the landing site and subsequently every day during the rehabilitation.
(iii) Anthropometry. Height of the astronaut was measured post-landing on R0 (preferably) or R+1 day.
(iv) Psychological assessment. It was done on R+1 and R+10 days privately by the Mission Psychologist.
(v) Skin photodocumentation. Photography of skin is necessary, especially of those parts that were exposed and were in contact with harness systems of the devices in space stations and launch/re-entry vehicles. A comparison was made between the pre- and post-flight photographs of those areas.
(vi) Sensorimotor evaluation. It was carried out on R+1 and R+7 days at the Vestibular laboratory. The evaluation consisted of a functional mobility test, pilot field test, and dynamic post-urography.
(vii) Ocular assessment. It was done on R+3 day by the ophthalmologist. The tests included assessment of visual acuity, color vision, contrast sensitivity, fundoscopy, optical coherence tomography, optical biometry, orbital ultrasonography (USG) (B scan), and orbital magnetic resonance imaging (MRI).
(viii) Audiological assessment. Audiometry and tympanometry were carried out on R+6 day.
(ix) Cardiorespiratory assessment. Resting electrocardiogram was obtained immediately post-landing. Spiro-ergometry was performed on R+5 day for assessment of VO_2 max.
(x) Nutritional check. Crew members undergo nutritional assessment testing on an agency-specific basis according to the specifications and schedule operationalized by the space agency. Nutritional assessment included determination of typical dietary intake using a standard dietary assessment questionnaire. Blood samples and 48 hr void-by-void urine samples were collected for determination of nutritional status.
(xi) Radiation assessment. Post-flight, the individual dosimeters of the crew were sent for analysis.
(xii) Sleep assessment. Quality of sleep post-flight was assessed during medical examination by a flight surgeon in the morning.
(xiii) Dental examination. Dental examination was performed after the 1st week of rehabilitation.
(xiv) Radiological investigations. USG of the jugular vein was carried out on landing day. USG abdomen, pelvis, and thyroid were carried out as part of pre-flight medical evaluation. Post-flight, these investigations are done only if clinically indicated. MRI Brain, orbit, and spine were carried out on R+3 day.

POST-FLIGHT PHYSICAL REHABILITATION

The rehabilitation team comprised a Flight Surgeon, an Exercise Specialist, and a Physiotherapist. The activities performed during 1st week of physical rehabilitation are tabulated as under:-

Day	Activity	Duration
R0 and R+1	Massage therapy	At the discretion of crew, Flight Surgeon, and Physiotherapist
R+2 to R+7	Physical reconditioning (i) Warm up on cross-elliptical trainer, rowing, and bicycle ergometers (ii) Back and lower limb activation exercises (iii) Gait, stability, and lower limb coordination assessment (iv) Stability and Posture exercises in the form of ball throwing and rope swinging while walking. (v) Stretching using therapeutic bands	02 hours
	Massage therapy	01 hour

The sessions in the subsequent week included Hydrotherapy, that is, a workout in the swimming pool (such as aqua jogging and playing ball games in water), in addition to the ongoing exercises in the gymnasium and massage therapy. The astronaut was advised not to undertake any jogging, running, or jumping activity till deemed fit by the Rehabilitation team.

Objective assessment of the status of anti-gravity core body muscles, namely, multifidus and transversus abdominus, was performed through an ultrasound scan by the Physiotherapist. The characteristics of these muscle groups with respect to their girth and composition were looked into and compared with pre-flight images.

After every reconditioning session, the rehabilitation team engaged in a private conference to discuss the physical conditioning status of the crew on that day and plan subsequent rehabilitation activities for the next day.

DISCUSSION

The post-flight reconditioning program is designed to promote recovery of the crew members from the deconditioning experienced in μG, which was not successfully mitigated by existing countermeasures on board ISS. Flight surgeons and other medical experts continuously monitor the astronauts during the post-flight period. Their day-to-day schedule, workloads, and activity levels are adjusted accordingly to protect them against musculoskeletal injury and other health complications that might arise before the completion of the re-adaptation process.[13]

The post-flight medical status of the crewmembers needs to be assessed immediately to prescribe appropriate medical care. This is subsequently followed by a detailed medical examination at an approved medical facility. The impact forces in a splashdown are considered similar to a crash landing.[14] Hence, spinal care is of prime importance during recovery as well as initiation of rehab protocol. Further, the course of post-flight medical evaluation proceeds as per NASA guidelines, taking into consideration the status of the crew post-landing.

Concerns post-landing include entry motion sickness (EMS), orthostatic intolerance, and neurovestibular incoordination. EMS had been reported by the US and Russian space agencies in missions as short as 4 days. For mission durations of 20 days or less, functional recovery is observed in about 7 days.[15] The flight surgeon is available on the ground to administer anti-nausea medications, provide support to maintain balance on the ground, help in showers, and assist with science experiments, baseline data collection, etc.

Post-flight medical assessments replicate most of the pre-flight preventive and occupational medicine tests. In case of post-flight medical evaluation being normal, daily general and systemic examinations are performed by the flight surgeon during the rehabilitation phase to assess the health status of the crewmembers and their adjustment back to the 1G environment. In addition, evaluation by Clinical Specialists, Psychologist, and Nutritionist proceeds as per schedule.

The purpose of post-flight physical rehabilitation is to ensure the safety of the returning crew members and recondition their physical status to pre-flight levels. Assessment of fitness levels is conducted based on NASA standards and guidelines.[12] However, there is no "blueprint rehabilitation protocol,"; rather, it is customized as per the capability and daily physical status of the individual crew member post-landing.

The astronauts use their hands instead of legs for locomotion in the ISS. These patterns of movement, which were adapted to the μG environment, must be "unlearned" on their return to Earth. They need to re-acquire the gravity-dependent reflexes and movement patterns so as to successfully perform activities like jumping.[11] The transition back to gravity also results in overall muscle stiffness, thereby compromising their flexibility post-landing.[16] While their body is re-adapting to Earth's gravity, the exercise specialists maintain a conventional approach while applying external loads since the crew has not fully restored their postural stability.[4] Hence, relaxation and flexibility training are implemented in the post-flight exercise protocol[16], and the crew is advised to avoid jumping activities during the initial phase of the rehab program.

Physiotherapy plays an important role in addressing any mission-induced physical problems and returning the crew to their pre-flight condition without risking the development of pain or injuries associated with re-adaptation and load bearing.[16] Objective assessment of anti-gravity core body muscles (viz., multifidus and transversus abdominus) and their comparison with pre-flight status is helpful in charting the course of physiotherapy and exercise protocol. Flexibility exercises of the lower extremities, ball games, concentric resistive exercises, etc., are used to challenge balance movement control and improve hand-eye coordination.[17] Finally, workout sessions in the swimming pool (Hydrotherapy) provide the crew with an environment of neutral buoyancy, which mimics the weightlessness of the μG environment. This enables them to perform dynamic exercises using water resistance in a controlled environment, which is helpful for proprioception, control of limb movements, and endurance training of local musculature.[11]

LESSONS LEARNED

1. Post-flight medical evaluation of the astronaut is performed as per NASA guidelines for LDMs. It is imperative to have a post-flight medical evaluation protocol for Astronauts participating in Gaganyaan Mission, based on the mission duration.
2. Periodic pre-flight assessment of the medical and physical fitness status of the Astronaut trainees is essential to maintain readiness for space flight. Sensorimotor evaluation by Pilot Field test, Functional Mobility test,

and Dynamic Posturography are important to be carried out during pre-flight medical evaluation and compared with post-flight assessment. In addition, assessment of anti-gravity muscles, namely, multifidus and transversus abdominus needs to be performed in periodic as well as pre-flight medical evaluation of Astronaut Designates for Gaganyaan Mission.

3. Role of the Physiotherapist is important in USG assessment of anti-gravity muscles, providing massage therapy, and conducting physiotherapy exercises**.** The tasks undertaken by the Physiotherapist require professional expertise in terms of having knowledge of the target muscle group activity and training those muscles to avoid their underutilization post-landing.
4. The role of the Flight Surgeon is crucial in the rehabilitation program, since he is the doctor accompanying the astronauts since his pre-flight evaluation. Any deviation from his pre-flight values would entail customization of the physical and medical evaluation protocols during this post-flight period. The Flight Surgeon, along with the Exercise Specialist and Physiotherapist, should ensure that the astronaut is not over-exhausting himself, especially during the immediate post-flight exercise sessions. Any indication of subclinical musculoskeletal injury or potential for such injury should be discussed by members of the Physical Rehabilitation Team, and subsequent rehabilitation protocol should be planned.

CONCLUSION

The Post-flight rehabilitation program described in this paper has stood the test of time and has achieved its aim of restoring the physical condition of the astronaut returning from LDMs to pre-flight levels. The deleterious effects of short duration space flight on human physiology are less as compared to LDMs, and the time taken to recover after landing is also shorter. Nevertheless, the astronaut would require proper medical care and reconditioning exercises to recover from these effects. Considering individual variations in the astronaut population, it is necessary to have a customized protocol for the Indian Astronauts based on the mission duration and their physiological status post-landing/ splashdown.

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Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI.

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