Russian system of countermeasures on ISS

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Main adverse effects of hypogravity on human body systems

- Skeletal bones demineralization;
- Deconditioning, atrophy and structural changes in the muscle apparatus;
- Cardiovascular deconditioning;
- Degradation of general physical performance;
- Loss of orthostatic tolerance;
- Disorders in coordination of movements (posture, locomotion, target acquisition);
- Reduction of g-load tolerance.
THE RUSSIAN SYSTEM OF COUNTERMEASURES

- PHYSICAL METHODS AIMED TO DIMINISH FLUID REDISTRIBUTION IN WEIGHTLESSNESS (LBNP, OCCLUSIVE CUFFS) AND DURING READAPTATION TO 1G (ANTI-G-SUIT);

- PHYSICAL EXERCISES AIMED TO LOAD THE MUSCULAR AND CARDIOVASCULAR SYSTEMS, TO STIMULATE THE PROPRIOCEPTIVE SYSTEMS AND TO MAINTAIN FUNCTIONALITY OF THE POSTURE AND LOCOMOTION CONTROL SYSTEMS;

- MEASURES FOR FLUID RETENTION - WATER-SALT SUPPLEMENTS;

- PHARMACOLOGICAL ABATEMENT OF NEGATIVE VESTIBULAR, METABOLIC AND OTHER REACTIONS TO WEIGHTLESSNESS.
Countermeasure currently available on the ISS

- Treadmill (TVIS)
- Bicycle ergometer (VB-3)
- Force training device (NS-1)
- Expanders (bungees)
- Electromyostimulator (Tonus-3)
- Electromyostimulator (Stimul-01 NCh)
- Axial loading suit PENGUIN
- Pneumatic vacuum suit CHIBIS (LBNP)
- Anti-G suit CENTAURUS
- Bracelet device (Bracelet-M)
- Water-salt supplements
<table>
<thead>
<tr>
<th>Day</th>
<th>Goal</th>
<th>WWork load</th>
<th>Intensity of load</th>
<th>Energy expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maintenance of high velocity characteristics of muscle and of orthostatic tolerance</td>
<td>LLow</td>
<td>Submaximal and maximal</td>
<td>380-420 k/Cal (1591-1758 k/J)</td>
</tr>
<tr>
<td>2</td>
<td>Maintenance of strength-velocity properties of skeletal muscles</td>
<td>MMiddle</td>
<td>Middle</td>
<td>450-500 k/Cal (1884-2093 k/J)</td>
</tr>
<tr>
<td>3</td>
<td>Maintenance of endurance properties and of movement coordination</td>
<td>HHigh</td>
<td>Small</td>
<td>550-600 k/Cal (2303-2512 k/J)</td>
</tr>
<tr>
<td>4</td>
<td>Active rest (exercises of cosmonaut’s choice)</td>
<td>SSmall</td>
<td>ad libidum</td>
<td>about 150 k/Cal (628 kJ)</td>
</tr>
</tbody>
</table>
The onboard veloergometer provides a standard loading on the cardiovascular system. With an assortment of modes available - passive, active, and free, the veloergometer provides the capability of performing discrete loading with a power from 50 to 225 Wt given a pedaling frequency of 40-80 rpm.
The axial loading suit compensates in Space the load deficit in the musculoskeletal system and also the deficit of weightbearing and proprioceptive afferentation.

The tension of the elastic elements of the suit creates the «compressive» load along the body’s longitudinal axis up to 40 kg.
PREVENTIVE VACUUM SUIT "CHIBIS"

- Low Body negative Pressure (LBNP) created by the vacuum suit CHIBIS is used to fight detraining effects of microgravity on mechanisms of orthostatic tolerance.
The suit prevents pooling of body fluids in the legs and orthostatic collapse during and after landing and on the first days of readaptation to the Earth’s gravity.
Schedule of the Russian program of countermeasures during long-duration ISS mission

1. **BEGINNING OF MISSION** (flight days 1-10): occlusive cuffs (p<50 mmHg, 20-30 minutes) and physical training at 50% of the prescribed loading.

2. **PERIOD OF STABILIZATION**: two 1-hr. training sessions a day with the use of tread mill, bicycle ergometer, expanders, force loading device or electromyostimulation and “Penguin” facultatively.

3. **PRE-EVA**: same training sessions with the emphasis on manual pedaling.

4. **END OF MISSION** (-30 last days): two tread mill training sessions a day; 2-4 preliminary and two final (main) LBNP sessions; water-salt supplements (0.9% NaCl, 18-20 mL per kg of body mass, 3-4 times at the final 12-20 hours on mission).

5. **DEORBITING AND INITIAL DAYS OF READAPTATION**: ANTI-G SUIT “Centaur”
## Performance of PhT by Russian cosmonauts in ISS SFs

<table>
<thead>
<tr>
<th>N</th>
<th>SF days</th>
<th>PhT once a day</th>
<th>PhT twice a day</th>
<th>TVIS</th>
<th>Bicycle</th>
<th>IRED</th>
<th>Cuffs</th>
<th>“Penguin”</th>
<th>Tonus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>142</td>
<td>1-100 days 100%</td>
<td>From 110th d. of SF – 100%</td>
<td>Walking from 11th d.; running – up to 7 miles from 47th day, with 40 kg loading</td>
<td>45-126 days Bi failed</td>
<td>Yes, intensively</td>
<td>no</td>
<td>Yes, without adequate loading</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>142</td>
<td>rare</td>
<td>mostly</td>
<td>The same, V-up to 9 km/h, loading up to 50 kg</td>
<td>-</td>
<td></td>
<td>-</td>
<td>Yes, not intensively</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>167</td>
<td>First 50 days</td>
<td>The second half Harpyuka</td>
<td>Repairment up to 56 d., the last month 2 times, V-9-11 km/h, loading 46 kg</td>
<td>yes</td>
<td>yes+expanders in FGB</td>
<td>no</td>
<td>Yes, with a good loading</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>129</td>
<td>40%, 15% no PhT</td>
<td>45%</td>
<td>Up to 20 d. – no TVIS SLD, V – up to 12 km/h</td>
<td>yes</td>
<td>-</td>
<td></td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>129</td>
<td>100%</td>
<td>-</td>
<td>Reduced usage</td>
<td>yes</td>
<td>Yes, intensively</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>196</td>
<td>100%</td>
<td></td>
<td>No TVIS SLD up to 137 d., loading – about 50 kg, low intensity and volumes</td>
<td>yes</td>
<td>No; expanders</td>
<td>First 3-4 days of SF</td>
<td>Yes, not adequate regimen 6-8 hrs/day</td>
<td>Yes, once a week</td>
</tr>
<tr>
<td>N</td>
<td>SF days</td>
<td>PhT once a day</td>
<td>PhT twice a day</td>
<td>TVIS</td>
<td>Bicycle</td>
<td>IRED</td>
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<td>Tonus</td>
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<td>--------------------------</td>
</tr>
<tr>
<td>7</td>
<td>185</td>
<td>0%</td>
<td>100%</td>
<td>Passive regimen -intensity up to 13 km, workload up to 10 km</td>
<td>yes</td>
<td>Yes+NS-1+middle size expander</td>
<td>yes</td>
<td>Yes, the whole working day</td>
<td>Yes, 10-12 times per flight</td>
</tr>
<tr>
<td>8</td>
<td>185</td>
<td>0%</td>
<td>100%</td>
<td>Low intensities and workloads. Last 30days – TVIS 2 times a day</td>
<td>yes</td>
<td>intensively</td>
<td>yes</td>
<td>Yes, regularly</td>
<td>Yes, 10-12 times per flight</td>
</tr>
<tr>
<td>9</td>
<td>195</td>
<td>0%</td>
<td>100%</td>
<td>Low intensity, 2-5 m/h, aerobic running, loading 40 kg from shoulders, at the end – TVIS 2 times a day</td>
<td>yes</td>
<td>No, NS-1 regularly</td>
<td>50% of SF</td>
<td>no</td>
<td>Occasionally</td>
</tr>
<tr>
<td>10</td>
<td>161</td>
<td>0%</td>
<td>100%</td>
<td>TVIS SLD – 30 days before landing, V – 10-11 km/h</td>
<td>yes</td>
<td>no</td>
<td>Yes, for a long time</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>11</td>
<td>181</td>
<td>50%</td>
<td>50%</td>
<td>V – 2-4 m/h, workload 100%, walking/running - 1/3, loading 45kg, at the end 50 kg</td>
<td>yes</td>
<td>No, NS-1</td>
<td>First 2 weeks of SF</td>
<td>4-5 hrs/day 1 month before landing</td>
<td>1 month before landing</td>
</tr>
<tr>
<td>12</td>
<td>188</td>
<td>0%</td>
<td>100%</td>
<td>V – below 7 km/h, low loading</td>
<td>Yes, with MO-5 regimen</td>
<td>Highly intensive</td>
<td>First 2-3 weeks of SF</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

LBPN, water-salt loading, “Centaurus” were used before and during landing according to the standard protocol by all cosmonauts.
Monitoring of countermeasures’ efficacy in SF

REGISTRATIONS OF PHYSICAL EXERCISES IN 4 DAYS MICROCYCLE

TEST MO-3
Includes 11 minutes locomotor test and 2 test with bungee cords

Scheme of locomotor test

Parameters analyzed:
- Overall distance;
- Walking and running distances;
- Velocity on the steps;
- Heart rate on the steps and 3 minutes after stop;
- Lactate concentration before and after the test.

BEFORE EVA – HAND BICYCLING WITH THE INTENSITY 150 WTS

TEST– MO-5
Data of clinical monitoring

Characteristics analyzed:
- time of bicycling up to fatigue;
- maximal heart rate.
Alterations of characteristics of MO-3 during long term SFs in 5 members of ISS crews

<table>
<thead>
<tr>
<th>Before flight</th>
<th>Flight, month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>Speed of locomotion, fast running</td>
</tr>
<tr>
<td>158.0</td>
<td>7.8</td>
</tr>
<tr>
<td>160.0</td>
<td>8.3</td>
</tr>
<tr>
<td>162.0</td>
<td>8.8</td>
</tr>
<tr>
<td>164.0</td>
<td>9.3</td>
</tr>
<tr>
<td>166.0</td>
<td>9.8</td>
</tr>
<tr>
<td>168.0</td>
<td>9.3</td>
</tr>
<tr>
<td>170.0</td>
<td>9.8</td>
</tr>
<tr>
<td>172.0</td>
<td>9.3</td>
</tr>
<tr>
<td>174.0</td>
<td>9.8</td>
</tr>
</tbody>
</table>

HR: Heart Rate
Speed: Speed of locomotion, fast running
Changes of pulmonary ventilation during “fast running” step in long term SFs in 5 ISS crew members
Changes of lactate blood concentration during MO-3 performance in STs on ISS; the mean data of 5 crew members.
Changes of relations of main MO-3 characteristics during long term SF in ISS crew members

Data of cosmonaut A

Data of cosmonaut B
## List of sensory-motor clinico-physiological evaluation studies (CSE) in Russian cosmonauts in ISS SFs

<table>
<thead>
<tr>
<th>Category</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone characteristics</td>
<td>Densitometry</td>
</tr>
<tr>
<td>Muscle properties</td>
<td>Isokinetic dynamometry of hip and leg muscles</td>
</tr>
<tr>
<td></td>
<td>Tendometry with tetanic contractions of leg extensors</td>
</tr>
<tr>
<td></td>
<td>Biopsy of m.Soleus</td>
</tr>
<tr>
<td>Coordination</td>
<td>Stretch (Achill) reflex</td>
</tr>
<tr>
<td></td>
<td>Equilibrium (pushing test)</td>
</tr>
<tr>
<td></td>
<td>Control of accuracy of efforts gradation</td>
</tr>
<tr>
<td></td>
<td>Eye movements control</td>
</tr>
<tr>
<td></td>
<td>Locomotions</td>
</tr>
<tr>
<td>Vestibular system characteristics</td>
<td>”Sensory adaptation” battery</td>
</tr>
</tbody>
</table>
Bone mineral mass changes (%) after Mir and ISS 6 Mo flights (in the same cosmonauts gravitational trend for Mir data) (N=8)
Histogram of lumbar spine bone mineral density changes in ISS space flights (n =12)
Histogram of femoral neck bone mineral density changes

In ISS space flights (n=12)
Lumbar spine bone mineral changes in two cosmonauts after Space flights
Proximal femur bone mineral changes in two cosmonauts after space flights
Biopsy of m.soleus

Methods:
- Muscle samples were obtained from m. soleus of crewmembers before (L-60) and after spaceflight (R+1) by means of needle biopsy.
- The immunofluorescent technique was applied for analysis of myosin heavy chain (MHC) isoforms. The monoclonal antibodies against slow (MHCs) и fast (MHCf) isoforms were used (Novocastra Laboratories).
- Image analysis was performed by means of Leica Quantimet system.

Results:
- Those crewmembers who had performed countermeasure exercises in volume and intensity for ankle extensors low than recommended, were observed to reveal sufficient decline in soleus fiber sizes.
- Those crewmembers who had performed adequate exercises for ankle extensors atrophic changes in soleus fibers were not found.
MHC slow fibers cross-sectional area

- \( \mu m^2 \)
- 1subj
- 2subj
- 3subj
- 4subj
- 5subj

- MHC I bef
- MHC I aft
MHC fast fibers cross-sectional area

μm²

1subj  2subj  3subj  4subj  5subj

MHC IIa bef
MHC IIa aft
Research and Development of Future countermeasures

Goals:

-- Optimization
  - Increase of countermeasures efficacy:
  - Enhancement of training facilities;
  - Widening the range of active and passive countermeasure means;
  - Increase of comfort of training devices;
  - Development of environmental resistive training capabilities.

-- Automation
  - Development of the autonomous system of training management;

-- Increase of reliability

-- Upgrading the technologies and approaches of inflight evaluation of countermeasures efficacy
The main advantage of the Penguin load measuring system is the existence of objective data about the loads to cosmonaut’s body, that is provided by the suit.

Redesigned components:
- Penguin-M will be outfitted with an automatic system for measuring tension of suit bungees. The system has an interface with onboard PC.

Status:
- The system passed the in-flight testing onboard the ISS.
“Penguin” Suit with the Load Measuring System

Computer-based LMS provides:

- Data sampling at a preset frequency (10 - 50 Hz);
- Display of tabulated actual loads to individual bungees and the total load value produced by the groups of bungees;
- Possibility to enter brief comments;
- Data retention.
New countermeasure device.
Multifunctional strength exercise device MDS
Eccentric, concentric and isometric exercises for arms, legs and the back.

**Types of exercise:**
- Rowing
- Body flexion
- Body extension
- Forearm flexion/extension
- Leg press
- Bench press;
- Seated press;
- chin-up simulation.

**Status:**
Now is under physiological testing in the 105-d experiment.
New countermeasure device. Treadmill BD-2

Support reaction gauge

The treadmill allows human to walk and run:

- in motorized and non-motorized modes;
- With a speed from 2.4 to 20 km/hr;
- Having axial loading ranging from 40 to 70 kg;
- Using the vibroisolation system that provides the mechanic isolation from the station.
PHYSIOLOGICAL CONTROL OF MUSCLE PLASTICITY IN WEIGHTLESSNESS

Acute phase

- Disuse of slow-twitch fibers
- Support unloading
- Motor unloading
- Disuse of fast-twitch fibers

Structural phase

- Inactivation of slow motoneurons
- Spindle inactivation
- Functional "shortening"
- Atonia
- Stimulation of protein degradation
- Protein synthesis inhibition
- Decline of oxidative capacities
- Atrophy of slow-twitch fibers
- Atrophy of fast-twitch fibers

Decline of oxidative capacities
Decline of muscle contractile properties
Compensator of support unloading KOR-01-N

Status:
Autonomous testing at the designer’s site.
Prototype was exposed to physiological testing in a 7-d dry immersion experiment.

1. Two modes of mechanic stimulation:
   a. walk-1 – 75 steps/min;
   b. walk-2 – 120 steps/min.

2. Pressure in air bladders – 0.15 to 0.5 kgf/cm²

3. “Rigid” and “flexible” operating mode.
Electrical myostimulator is intended for low-frequency, low-amplitude stimulation of leg and back muscles.

Main components:
Electromyostimulator and suit.

Status:
Included into the ISS onboard countermeasure system.
ADVANCED COUNTERMEASURES UNDER DEVELOPMENT (candidates for application by Mars exploration crew)

1. Short-arm centrifuge;
2. Automated expert physical training control system;
3. Environmental resistive training capabilities