Human Cardiovascular Adaptation to Short-term Weightlessness

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Example of cephalad fluid shift

Pre-flight press briefing

FD-2
Inflight: Fluid shift

Cardiac preload:
- Central venous pressure?
- Blood volume?
- Stroke volume – cardiac output?

Cardiac afterload:
- Blood pressure
- Systemic vascular resistance
- Baroreflexes – sympathetic nervous ac.

Cardiac muscle mass
Central venous pressure in space

<table>
<thead>
<tr>
<th>CVP</th>
<th>Seated</th>
<th>Supine, legs-up</th>
<th>0 G</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm H₂O, N = 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.4</td>
<td>15.0</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

Buckey et al.,
J. Appl. Physiol.
Foldager et al. J. Appl. Physiol. 81: 408-12, 1996
Heart distension in 0 G
Mechanism?

The pressure in the inter-pleural space surrounding the heart is decreased by 0 G.

*Therefore:*

This pressure must also be measured!
Mechanism?

Cardiac distension pressure
Mechanism?

Atrial distension pressure
Mechanism?

Atrial distension pressure = CVP!
TBW results differ between studies, however all spaceflight studies are low “n” studies. Regardless of mechanism, it is known that PV is decreased.

Figure 7. Mean TBW during space flight. Data are adjusted to 70 kg body mass. The error bars represent the standard error of the mean of the four observations on each of the five mission periods.
Plasma volume losses are similar after short and long-duration spaceflight
Where does the plasma volume go?

Fig. 3. Mean fluid compartment volumes before and during space flight. Data from Leach and colleagues (Leach et al., 1996) (N=6). TBW, total body water; ECF, extracellular fluid; PV, plasma volume; ISF, interstitial fluid; ICF, intracellular fluid; FD7–8, flight days 7–8.

Fig. 4. Mean percentage change in fluid compartment volumes from pre-flight to flight days 7–8. Data from Leach and colleagues (Leach et al., 1996) (N=6). ICF, intracellular fluid; ISF, interstitial fluid; ECF, extracellular fluid; PV, plasma volume.

Cardiac output

Prisk et al.
J. Appl. Physiol.
Cardiac Output
Mean over 4 hrs (l/min)

1 G seated 0 G (1 wk)
Mean arterial pressure
Mean over 4 hrs (mm Hg)

1 G seated

0 G 1 wk
Systemic Vascular Resistance
Mean over 4 hrs (mmHg•min/l)
Compared to the supine position?
Cardiac Output
Mean over 4 hrs (l/min)
Systemic Vascular Resistance
Mean over 4 hrs (mmHg•min/l)
Figure 1. Baroreflex testing The left panel shows astronaut Rhea Seddon performing baroreflex testing on herself during the SLS-1 mission.

Figure 3. Mean ± 95% confidence intervals for preflight and inflight vagal baroreflex relations. Confidence limits for carotid distending pressures are obscured by the symbols.

Mean 4-h plasma Noradrenaline (pg/ml)

* Norsk et al.
J. Appl. Physiol.
78: 2253-59, 1995
Plasma Renin (pg/ml)

Norsk et al.
J. Appl. Physiol.
78: 2253-59, 1995
Cardiac MRI was conducted pre-flight and post-flight: 10 days of microgravity exposure. It is unclear on what post-flight day MRI data was acquired and there was no follow-up.

Postflight:

- Orthostatic tolerance
- Aerobic exercise capacity
Presyncope increases with Flight Duration

Incidence of Presyncope on Landing Day, %

** P < 0.01

- short duration stand n=6
- short duration tilt n=20
- long duration tilt n=6

- short duration stand
- short duration tilt
- long duration tilt
Isotonic Fluid Load

The operational fluid load (salt tablets and water before landing) was imposed to correct the dehydration. Used static stand test and cardiovascular index of deconditioning (CID) to quantify results.

However, the efficacy of the operational fluid load was not determined: it is unknown how much plasma volume is actually replaced.

Does not restore plasma volume to pre-flight levels: currently, there is approximately a 9% loss.
Orthostatic intolerance:

Mitigated by:

- Oral salt and fluid loading
- Antigravity garment
- Additional clinical treatment
Florinef® Does not Correct Post-spaceflight Orthostatic Hypotension

<table>
<thead>
<tr>
<th>Incidence of Presyncope (%)</th>
<th>Control (n=18)</th>
<th>Florinef® (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
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<td>20</td>
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<tr>
<td>40</td>
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<tr>
<td>50</td>
<td></td>
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</tbody>
</table>
Table 2. Preflight measurements

<table>
<thead>
<tr>
<th></th>
<th>Presyncopal on Landing Day (n=8)</th>
<th>Nonpresyncopal on Landing Day (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supine</td>
<td>Standing</td>
</tr>
<tr>
<td>Plasma norepinephrine, pg/ml</td>
<td>213 ± 28</td>
<td>467 ± 42</td>
</tr>
<tr>
<td>Peripheral vascular resistance, mmHg·l⁻¹·min</td>
<td>15.5 ± 0.9*</td>
<td>22.9 ± 1.8*</td>
</tr>
<tr>
<td>Diastolic pressure, mmHg</td>
<td>66 ± 2†</td>
<td>69 ± 4†</td>
</tr>
<tr>
<td>Systolic pressure, mmHg</td>
<td>109 ± 3*</td>
<td>99 ± 4†</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>62 ± 2†</td>
<td>81 ± 5†</td>
</tr>
<tr>
<td>Stroke volume, ml</td>
<td>86 ± 5</td>
<td>45 ± 5</td>
</tr>
<tr>
<td>Cardiac output, l/min</td>
<td>5.3 ± 0.5*</td>
<td>3.6 ± 0.4*</td>
</tr>
<tr>
<td>Mean flow velocity (middle cerebral artery), cm/s</td>
<td>58.9 ± 5.7</td>
<td>51.2 ± 2.5*</td>
</tr>
<tr>
<td>Cerebral vascular resistance, mmHg·cm⁻¹·s</td>
<td>1.5 ± 0.2</td>
<td>1.1 ± 0.2*</td>
</tr>
<tr>
<td>Plasma epinephrine, pg/ml</td>
<td>19 ± 3</td>
<td>30 ± 3</td>
</tr>
<tr>
<td>Plasma renin activity, ng·ml⁻¹·h⁻¹</td>
<td>1.7 ± 0.4</td>
<td>2 ± 0.5</td>
</tr>
<tr>
<td>Plasma volume, liters</td>
<td>3.2 ± 0.2</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SE; n, no. of subjects. Supine, standing, and standing-supine difference measurements for all variables (plasma volume was only measured supine) separated into presyncopal and nonpresyncopal groups before flight (average of 2 preflight data sessions). *P ≤ 0.05 between groups. †P ≤ 0.01 between groups.

Fritsch-Yelle, JM. et al. 1996
Table 1. Landing day measurements

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<th>Nonpresyncopal on Landing Day (n = 21)</th>
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<tr>
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<td>Supine</td>
<td>Standing</td>
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<tr>
<td>Plasma norepinephrine, pg/ml</td>
<td>330 ± 67</td>
<td>420 ± 46*</td>
</tr>
<tr>
<td>Peripheral vascular resistance, mmHg·l⁻¹·min⁻¹</td>
<td>16.0 ± 1.3</td>
<td>22.9 ± 2.5*</td>
</tr>
<tr>
<td>Diastolic pressure, mmHg</td>
<td>74 ± 4</td>
<td>61 ± 4†</td>
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<tr>
<td>Systolic pressure, mmHg</td>
<td>110 ± 4*</td>
<td>80 ± 3†</td>
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<tr>
<td>Heart rate, beats/min</td>
<td>72 ± 5*</td>
<td>114 ± 8†</td>
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<tr>
<td>Stroke volume, ml</td>
<td>78 ± 4</td>
<td>28 ± 2</td>
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<tr>
<td>Cardiac output, l/min</td>
<td>5.5 ± 0.3</td>
<td>3.3 ± 0.3</td>
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<tr>
<td>Mean flow velocity (middle cerebral artery), cm/s</td>
<td>52.4 ± 4.7</td>
<td>40.0 ± 2.9</td>
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<td>Cerebral vascular resistance, mmHg·cm⁻¹·s⁻¹</td>
<td>1.7 ± 0.3</td>
<td>1.1 ± 0.1†</td>
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<tr>
<td>Plasma epinephrine, pg/ml</td>
<td>42 ± 5</td>
<td>66 ± 12</td>
</tr>
<tr>
<td>Plasma renin activity, ng·ml⁻¹·h⁻¹</td>
<td>2.7 ± 1.2</td>
<td>3.4 ± 1.5</td>
</tr>
<tr>
<td>Plasma volume, liters</td>
<td>2.7 ± 0.2</td>
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Values are means ± SE; n, no. of subjects. Supine, standing, and standing-supine difference measurements for all variables (plasma volume was only measured supine) are separated into presyncopal and nonpresyncopal groups on landing day. *P < 0.05 between groups. †P < 0.01 between groups.
Catecholamine Responses to Standing

Standing - Supine

Norepinephrine (pg/ml)

Standing - Supine

Epinephrine (pg/ml)

presyncopal women (n=4)

presyncopal men (n=6)

non-presyncopal men (n=22)

†p = 0.058  *p ≤ 0.05  **p ≤ 0.01

preflight

landing day

three days postflight
Maximum Oxygen Uptake Preflight, In-flight and Postflight (all max tests)

However -
Sympathetic nervous activity is high in space!
Vasodilatation and sympathetic activation how?
Hypothesis:

Seated

↓

0 G

- Venous return
- Cardiac output
- Vestibular disturbance
- Intracranial pressure
- Aortic stiffness
- Stress

↑ Central blood volume

↑ Natriuretic & vasodilatory peptides

↑

Vascular Distension of upper body

(−)

SVR

(−)

Blood pressure

SNA

(+)

Norsk & Christensen
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Co-authors

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