Effects of microgravity elicited by parabolic flight on abdominal aortic pressure and heart rate in rats

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Waki, Hidefumi, Tsuyoshi Shimizu, Kiyoka Katihira, Tadanori Nagayama, Masao Yamasaki, and Shin-Ichiro Katsuda. Effects of microgravity elicited by parabolic flight on abdominal aortic pressure and heart rate in rats. J Appl Physiol 93: 1893–1899, 2002. First published August 9, 2002; 10.1152/japplphysiol.01064.2001.—Abdominal aortic pressure (AAP), heart rate (HR), and aortic nerve activity (ANA) during parabolic flight were measured by using a telemetry system to clarify the acute effect of microgravity (μG) on hemodynamics in rats. While the animals were conscious, AAP increased up to 119 ± 3 mmHg on exposure to μG compared with the value at 1 G (95 ± 3 mmHg; P < 0.001), whereas AAP decreased immediately on exposure to μG under urethane anesthesia (μG: 72 ± 9 mmHg vs. 1 G: 78 ± 8 mmHg; P < 0.05). HR also increased during μG in conscious animals (μG: 349 ± 12 beats/min vs. 1 G: 324 ± 9 beats/min; P < 0.01), although no change was observed under anesthesia. ANA, which was measured under anesthesia, decreased in response to acute μG exposure (μG: 33 ± 7 counts/s vs. 1 G: 49 ± 5 counts/s; P < 0.01). These results suggest that μG essentially induces a decrease of arterial pressure; however, emotional stress and body movements affect the responses of arterial pressure and HR during exposure to acute μG.

SPACEFLIGHT INDUCES CARDIOVASCULAR deconditioning characterized by tachycardia and orthostatic hypotension when astronauts return to the Earth (5, 6, 27, 40). Several experiments simulating the conditions elicited under microgravity (μG) in humans suggest that the new circulatory condition may lead the neurohumoral regulation systems to adapt to the space environment (7, 8, 18, 19). This hypothesis, however, has not been adequately substantiated because data obtained in space are still too limited to understand the changes of hemodynamics and the process of adaptation of the cardiovascular regulation system during spaceflight. In fact, it is not easy to measure physiological parameters continuously over a period of spaceflight because the time available for life science research is extremely limited and surgical operations are sometimes required to obtain the cardiovascular parameters (4, 9, 11, 13).

In experiments using animals, investigators have reported that alteration in the cardiovascular system was also observed in rats after exposure to simulated μG (2, 24, 26, 37). In rats raised in space, our laboratory also recently observed an attenuation of the baroreceptor reflex (31, 39), which is known to be affected by spaceflight in humans (14, 15, 27). These findings show that the measurement of cardiovascular parameters of animals in space will help to elucidate the mechanisms of cardiovascular deconditioning observed in astronauts after spaceflight (5, 6, 27, 40). On the other hand, in parabolic flight experiments using aircraft, a useful method of producing short periods of μG conditions in the Earth’s environment, the changes of cardiovascular variables obtained in animals during μG are not the same as those in humans. Pump et al. (29) reported that arterial pressure decreased on exposure to μG compared with the values in supine position under 1 G. In conscious rats, however, Somody et al. (36) observed an increase in arterial pressure, which was measured in the aorta of the abdominal region via radiotelemetry (3), during μG produced by parabolic flight. From this inconsistency between humans and rats, the question arises as to the validity of measuring cardiovascular parameters of rats to understand the mechanisms of human cardiovascular alteration after spaceflight. The reasons for the differences between humans and rats have not been resolved, but it should be remembered that mental stress and body movement on exposure to an abnormal environment such as gravitational changes may affect the responses of hemodynamics in conscious animals (10, 12, 25).

General anesthetics such as urethane directly attenuate autonomic responses as well as eliminate mental stress and body movement (1, 34). As a result of other researchers’ suggestion that the simple physical effect of the lack of hydrostatic pressure directly affects cardiac performance (28), we believe that the use of anesthetics helps us to understand the essential effect of acute μG exposure on hemodynamics.

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The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked “advertisement” in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
The purpose of the present study was to reassess the essential effect of μG exposure elicited by parabolic flight on the cardiovascular variables in rats to examine the validity of space experiments using rats to further understanding of the human cardiovascular system under μG. Abdominal aortic pressure (AAP) and heart rate (HR) during parabolic flight were monitored continuously with radiotelemetry either during consciousness or under urethane anesthesia. Aortic nerve activity (ANA) was also measured under anesthesia to support the understanding of cardiovascular changes during acute μG exposure.

METHODS

Parabolic Flight Experiment

In this study, a jet airplane (MU-300 operated by Diamond Air Service, Nagoya, Japan) was used for the parabolic flight experiment. Parabolic flight maneuvers were attempted 9–12 times in one flight, which lasted 1 h, in the specified flight area of Japan. Each parabolic flight maneuver of the aircraft provided ∼20 s of 0.03 G. The μG condition was preceded by ∼2 G for 20 s and followed by ∼1.5 G for 20 s before the return to 1 G. The interval between each parabolic flight maneuver was ∼5 min. During the experiment, the room temperature in the plane was between 20 and 27°C and air pressure in the plane was 0.9 ± 0.1 atm.

Experimental Animals and Animal Care

Male Sprague-Dawley rats aged 6 wk (Charles River Japan) were used for this experiment. The care and treatment of the animals were carried out according to the Japanese Government Animal Protection and Management Law (no. 105), the Guidelines for Animal Experiments of Fukushima Medical University, and the Guiding Principles for the Care and Use of Animals in the Field of Physiological Sciences approved by the Council of the Physiological Society of Japan.

Experimental Protocol

Conscious animals (n = 12) were separately placed in Plexiglas cages (depth: 410 mm, width: 260 mm, height: 180 mm) installed on a special rack in the aircraft, and data in the freely moving animals were recorded by using a data acquisition system from just before takeoff to just after landing. Some animals (total number: 11) were anesthetized with an intraperitoneal injection of urethane (1.2 g/kg ip), a midline incision was made in the ventral region of the neck. The left sternocleidomastoideus and omohyoidus muscles were resected laterally to expose the left aortic nerve. The aortic nerve was placed on two urethane-coated silver wires (0.1-mm diameter, Unique Medical) under a dissecting microscope. The intact nerve and the electrodes (wires) were fixed with silicone resin (Sylgard 932 A and B, Wacker-Chemie). The electrical activity was amplified by using an amplifier (model AB-651J, Nihon Kohden) with a band-pass filter of 50–3,000 Hz and confirmed success of implantation. The transmitter for nerve recording was put on the back of rat by using a jacket, and the ends of two electrodes were connected to the transmitter.

Sinoaortic denervation. In six animals, sinoaortic denervation (SAD) was performed according to the Krieger method (23) immediately before the transmitters were implanted. Under general anesthesia (pentobarbital sodium, 50 mg/kg ip), a midline incision was made in the ventral region of the neck. The left carotid arteries were dissected and the common carotid artery were reflected laterally to expose the carotid arteries. The aortic nerves were isolated and sectioned bilaterally. The sympathetic trunks were bilaterally sectioned below the superior cervical sympathetic ganglion, and the superior laryngeal nerves were also bilaterally sectioned close to the larynx as possible to interrupt all other aortic nerve filaments. The fibers and connective tissues of the carotid artery were bilaterally stripped at the bifurcation area, and the area was painted with a small amount of 10% phenol in ethanol. The denervation was confirmed by using a baroreceptor reflex test; i.e., a bolus dose of phenylephrine (10–20 μg/kg) sufficient to increase

Implantation of transmitters for AAP. Each rat was treated as follows. The transmitter was implanted in the abdominal cavity ∼2 wk before the flight. The rat was anesthetized with an intraperitoneal injection of pentobarbital sodium (50 mg/kg). A midline incision of the abdominal wall was made while the animal was in the supine position, and the intestines were lapped with saline-moistened gauze sponges and moved aside by the retractor to allow good visualization of the abdominal aorta. The tip of the catheter (0.7-mm diameter, thin-walled thermoplastic membrane) of the transmitter (model TA11PA-C40; 15 × 20-mm diameter) was inserted into the abdominal aorta caudal to the root of the left renal artery. The transmitter was sutured to the ventral wall of the abdominal cavity along the long axis of the body, and the abdominal cavity was closed. Penicillin (1,000 U) was then injected into the muscles in the right thigh region, and the rat was returned to its home cage for recovery. When the animal stood in a four-footed posture under 1 G, the pressure transducer in the transmitter was positioned below the heart and the abdominal artery, indicating that the measured pressure showed a higher value than the true AAP and systemic blood pressure. In this study, however, we considered the measured pressure as AAP because the measured value shows the true AAP during μG.

Recording System

We used a telemetry system for recording AAP and ANA. The system for recording AAP consists of three basic elements: 1) a transmitter that includes a pressure sensor (model TA11PA-C40, Data Sciences International, St. Paul, MN); 2) a receiver (model RPC-1); and 3) an adapter (model R11CPCA) with an ambient pressure monitor (model APR-1) to output analog signals, which were relative to the barometric pressure in the cabin. The system for recording ANA consists of a transmitter (model DTT-101, Dia Medical System, Tokyo, Japan) and a receiver (model DTT-1000) with a band-pass filter of 50–3,000 Hz. A computer-based data acquisition system (MacLab/8s, AD Instruments and Power-Book 3400c, Apple Computer) was used to collect, display, store, and analyze the telemetered data. All equipment was set up on a special rack installed in the airplane. Pulse rate was calculated as HR from the pressure waves by off-line processing after the flight experiment. To quantify ANA, pulse counts were also calculated by off-line processing.

Surgical Procedures

Implantation of electrode for recording ANA. The electrode for recording ANA was implanted in four animals on the day of the flight. Under general anesthesia (urethane, 1.2 g/kg ip), a midline incision was made in the ventral region of the neck. The left sterno-encidomastoides and omohyoidus muscles and the common carotid artery were reflected laterally to expose the left aortic nerve. The aortic nerve was placed on two urethane-coated silver wires (0.1-mm diameter, Unique Medical) under a dissecting microscope. The intact nerve and the electrodes (wires) were fixed with silicone resin (Sylgard 932 A and B, Wacker-Chemie). The electrical activity was amplified by using an amplifier (model AB-651J, Nihon Kohden) with a band-pass filter of 50–3,000 Hz and confirmed success of implantation. The transmitter for nerve recording was put on the back of rat by using a jacket, and the ends of two electrodes were connected to the transmitter.

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pressure by at least 30 mmHg was injected from the right external jugular vein, and, if no bradycardia occurred, the rat was considered to be deafferented and used for this experiment.

Data Analysis

The averaged values at each gravity condition were used. All data are expressed as means ± SE. Gravity-dependent changes of cardiovascular variables were evaluated by repeated-measures ANOVA. If there was an interaction between group and gravity level, Scheffé’s post hoc test was used for multiple comparisons between all possible combinations to compare between groups. Because gravity-dependent changes were within factor, we used Scheffé’s post hoc test (repeated) to evaluate gravity-dependent changes within individual groups. The effect of repeated exposure onto the gravitational changes on the cardiovascular variables was also tested by using repeated-measures ANOVA.

RESULTS

General Behavior in Conscious Animals During Parabolic Flight

During 1 and 2 G, the animals kept a four-footed posture. On exposure to μG, however, they immediately floated, extending their limbs, and some animals were struggling to try to catch the ceiling or side walls of the cage.

Changes in AAP and HR in Conscious Rats During Parabolic Flight

Because 9–12 trials of parabolic maneuver were performed in each animal, the effect of repeated exposure on the gravitational changes on the cardiovascular variables were tested in conscious rats. However, no significant differences of gravity-dependent changes were observed at any time during the trials in either mean AAP (P = 0.68) or HR (P = 0.97). Thus the data obtained in all parabolic flight trials were used, and averaged values were calculated in each animal.

In the conscious condition (nerve intact, n = 6), AAP increased on exposure to 2 G. Mean AAP at 2 G (109 ± 2 mmHg) was significantly higher than that under 1 G (95 ± 3 mmHg; P < 0.001). On exposure to μG, AAP immediately increased to a level above the value obtained at 2 G (Fig. 1). The mean AAP at μG (119 ± 3 mmHg) was significantly greater than at 1 G (P < 0.001) and 2 G (P < 0.01). During 1.5 G produced on the way back to 1 G from μG, mean AAP (106 ± 1 mmHg) was still significantly higher than that under 1 G (P < 0.01). AAP then returned gradually to the pressure level before the trial as gravity reverted to 1 G (Figs. 1 and 2). HR in conscious animals changed only when exposed to μG. HR immediately increased on exposure to μG, and the value at μG (349 ± 12 beats/min) was significantly higher than either in 1 G (324 ± 9 beats/min; P < 0.01) or 2 G (325 ± 10 beats/min; P < 0.01; Fig. 2).

Fig. 1. Original recording of changes in abdominal aortic pressure (AAP) and gravity in the head-to-foot direction (Gz) during parabolic flight. A: recording from a conscious rat. B: recording from an anesthetized rat.

Fig. 2. Mean AAP and heart rate (HR) during parabolic flight. Values are means ± SE; n, no. of animals. μG, microgravity. *P < 0.05, **P < 0.01, and ***P < 0.001 compared with the value at 1 G. #P < 0.05 and ##P < 0.01 compared with the value at 2 G.
BLOOD PRESSURE AND HR DURING PARABOLIC FLIGHT IN RATS

Table 1. Averaged mean abdominal aortic pressure and heart rate throughout parabolic maneuver

|                  | Conscious | Conscious- | Anesthetized | Anesthetized-
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<td>(n = 6)</td>
<td>SAD (n = 6)</td>
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<td>SAD (n = 4)</td>
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<tr>
<td>Mean AAP, mmHg</td>
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<tr>
<td>HR, beats/min</td>
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<td>1896 BLOOD PRESSURE AND HR DURING PARABOLIC FLIGHT IN RATS</td>
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<tr>
<td></td>
<td>106 ± 2</td>
<td>125 ± 4</td>
<td>77 ± 3*†‡</td>
<td>67 ± 1†‡</td>
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<td></td>
<td>327 ± 5</td>
<td>365 ± 9</td>
<td>323 ± 11</td>
<td>307 ± 4</td>
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Values are means ± SE; n, no. of animals. AAP, abdominal aortic pressure; HR, heart rate; SAD, sinoaortic denervation. *P < 0.05, †P < 0.01 compared with conscious group. ‡P < 0.001 compared with conscious-SAD group.

Effects of Urethane Anesthetic on AAP and HR During Parabolic Flight

During parabolic flight, we did not find any symptom of cardiorespiratory changes that necessitated additional dosage of urethane anesthetics. AAP in anesthetized rats (n = 7) was significantly lower than in conscious rats throughout the parabolic maneuvers (Table 1). In contrast to AAP, HR in anesthetized rats did not differ from that in conscious rats (Table 1).

The patterns of the responses in AAP against gravitational changes in anesthetized animals were apparently different from those in conscious animals (Figs. 1 and 2). Mean AAP did not change during 2 G (1 G: 78 ± 8 mmHg vs. 2 G: 81 ± 9 mmHg), whereas it immediately decreased on exposure to μG. The value of mean AAP at μG (72 ± 9 mmHg) was significantly lower than that under either 1 G (P < 0.05) or 2 G (P < 0.01). On exposure to 1.5 G, AAP then recovered because mean AAP was the same as the baseline level at 1 G (Fig. 2). HR in anesthetized rats did not change throughout gravitational changes (Fig. 2).

Effects of SAD on AAP and HR During Parabolic Flight

During consciousness (n = 6), AAP and HR in SAD rats throughout parabolic maneuver tended to be higher than nerve-intact animals, whereas these values under anesthesia (n = 4) tended to be lower than those in anesthetized nerve-intact animals. However, the differences between nerve-intact and SAD rats were not statistically significant (Table 1). In SAD animals, the gravity-dependent changes in AAP and HR were similar to those in nerve-intact animals either during consciousness or under urethane anesthesia.

For the evaluation of the effects of SAD on AAP and HR in response to μG exposure, the changes of mean AAP and HR from the values measured in ether 1 G or 2 G were compared. However, these values are not different between nerve-intact and SAD groups either during consciousness or under urethane anesthesia (Table 2).

Changes in ANA in Anesthetized Rats During Parabolic Flight

ANA in anesthetized rats (n = 4) did not change on exposure to 2 G (1 G: 49 ± 5 counts/s; 2 G: 55 ± 5 counts/s), although it decreased on exposure to μG. The value at μG (33 ± 7 counts/s) was significantly lower than that at either 1 G (P < 0.05) or 2 G (P < 0.01). ANA increased again on exposure to 1.5 G and then returned to the level before the trial as gravity reverted to 1 G (Fig. 3).

DISCUSSION

Essential Effect of Acute μG Exposure on AAP and HR in the Rat

Because of the technical limitation of the parabolic flight, it is impossible to see the real effect of acute μG exposure from 1 G on the cardiovascular system without hypergravity-mediated effect. However, because the level of AAP at μG was higher than either 1 G or 2 G in conscious animals while being lower than either 1 G or 2 G under anesthesia, we believe that it is sufficient to simply state that acute μG exposure induces increased AAP in the conscious condition, but decreased AAP under anesthesia, compared with that at 1 G under each condition.

During consciousness, HR at μG was also higher than either 1 G or 2 G, whereas there were no changes in response to gravitational changes under anesthesia. Because ANA decreased as AAP fell in response to μG exposure, tachycardic effect mediated by the arterial baroreceptor reflex might be centrally attenuated by urethane anesthetics (1, 34). From these findings, we believe that the simple physical effect of μG exposure is a hypotension in the rat.

Table 2. Changes of mean abdominal aortic pressure and heart rate from 1 G to μG and from 2 G to μG

<table>
<thead>
<tr>
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<th>ΔMean AAP, mmHg</th>
<th>ΔHR, beats/min</th>
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<tr>
<td></td>
<td>From 1 G to μG</td>
<td>From 2 G to μG</td>
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<tr>
<td>Conscious condition</td>
<td></td>
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<tr>
<td>Nerve intact (n = 6)</td>
<td>23.8 ± 3.4</td>
<td>10.1 ± 2.8</td>
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<tr>
<td>SAD (n = 6)</td>
<td>23.5 ± 3.8</td>
<td>9.3 ± 4.2</td>
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<tr>
<td>Anesthetized condition</td>
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<tr>
<td>Nerve intact (n = 7)</td>
<td>−7.1 ± 1.4</td>
<td>−8.8 ± 0.6</td>
</tr>
<tr>
<td>SAD (n = 4)</td>
<td>−6.8 ± 1.0</td>
<td>−7.5 ± 1.2</td>
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Values are means ± SE; n, no. of animals. μG, microgravity; Δ, change. There are no significant differences between nerve-intact and SAD animals either during consciousness or under urethane anesthesia. Significant differences between conscious and anesthetized conditions are not shown.
response to $/H9262$ G. Whereas femoral arterial pressure decreased, on being rabbit, common carotid arterial pressure increased, Exposure in Anesthetized Rats

Plausible Mechanism of Increased AAP and HR by Acute $\mu$G Exposure in Conscious Rats

Because the direction of acute changes in AAP in response to $\mu$G exposure was the same as 2-G exposure, i.e., AAP increased in both cases, the changes in AAP under the conscious condition was apparently not gravity dependent. It is therefore plausible that AAP changes in response to gravitational changes did not contribute to the simple physical effect of gravitational changes on the cardiovascular system. Mental stress affects the cardiovascular variables (10, 12), and an excitement of the amygdala of the limbic system, which is known to be involved in generating emotional behavior patterns, may activate the dorsomedial hypothalamus with increases of arterial pressure and HR (35). Input from the somatic sensor, including the muscle work receptors, which are activated by body movement, also affects arterial pressure (25). Therefore, the emotional stress and body movement on exposure to sudden gravitational changes, either from 1 G to 2 G or from 2 G to $\mu$G, probably affected the responses of AAP and HR during consciousness. Furthermore, breathing patterns might also affect the response of arterial pressure during $\mu$G elicited by parabolic flight during consciousness (20, 30).

In our results, HR during consciousness increased with an increase of AAP on exposure to $\mu$G, showing inconsistency with a previous study by Somody et al. (36), who observed a decrease of HR on exposure to $\mu$G. In our experiments, the bradycardic effect of the baroreceptor-induced response to a large increase of AAP was probably canceled partially or hidden by the excitation effect of the sympathetic nervous system under conscious condition. The difference of the responses in HR between our findings and previous findings (36) might be due to differences in the flight pattern protocol and/or strain of the rat.

Plausible Mechanism of Decreased AAP by Acute $\mu$G Exposure in Anesthetized Rats

Our laboratory reported that, in the anesthetized rabbit, common carotid arterial pressure increased, whereas femoral arterial pressure decreased, on being placed in the head-down tilt position from the horizontal position (21, 32). Our laboratory has also previously found an increase in common carotid arterial pressure with a decrease in femoral arterial pressure under $\mu$G during parabolic flight in the anesthetized rabbit fixed in a sitting position (33). These findings show that the responses of hemodynamics to gravitational changes are different between the arteries, which are located above and below the heart along the gravity axis. This may be due to the differences in hydrostatic pressure between the arteries. In this study, we placed the arterial catheter into the abdominal aorta, which is almost the same height as the heart in a four-footed posture, while the pressure transducer was positioned below the heart and abdominal aorta along the gravity axis. This evidence indicates that the measured pressure was higher than the systemic blood pressure and real AAP at 1 G. Because of the absence of hydrostatic pressure under 0 G, the arterial pressure in the anesthetized rats may therefore have decreased on $\mu$G exposure. However, this may not be the main explanation for the mechanism of the acute decrease in AAP at $\mu$G exposure because the hydrostatic pressure between the heart and transducer in the rat under 1 G is, at most, only 2 mmHg, whereas AAP dropped up to 7.1 ± 1.4 mmHg in anesthetized animals. Moreover, ANA corresponded to AAP changes, i.e., ANA also decreased on exposure to $\mu$G, showing that systemic blood pressure apparently decreased on acute $\mu$G exposure.

Consistent evidence was obtained from human studies where decreased arterial pressure was observed in human subjects in supine position during $\mu$G elicited by the parabolic flight (29). By use of echocardiography, because an atrial distension was observed during $\mu$G (29, 38), it was suggested that the cardiopulmonary receptor reflex induced the hypotensive effects through a decrease of total peripheral resistance during $\mu$G (29). In this study, we found that the arterial baroreceptor reflex might be centrally attenuated by urethane anesthesia. It is therefore plausible that the cardiopulmonary receptor reflex might also be attenuated under anesthesia, suggesting that there is another mechanism for decreased arterial pressure in response to acute $\mu$G exposure. By using a hydraulic simulator of the human systemic circulation, Pantalos et al. (28) suggested that the simple physical effect of the lack of hydrostatic pressure induces a decrease in stroke volume and cardiac output. Thus hypotension in response to $\mu$G, which was observed in this study, might contribute to a decreased cardiac output.

Arterial pressure did not change during 2-G exposure under anesthesia. Interestingly, arterial pressure in supine human subjects also did not change during 2-G exposure (29). We cannot explain this from our present results. If changes in the arterial pressure are connected with the cardiac performance, we may be able to refer to the Frank-Starling mechanism. The atrial pressure may increase at 2 G and decrease at $\mu$G because of changes in hydrostatic pressure and/or changes in central venous pressure (36). On the basis of Starling curves, the effect of atrial pressure changes

Fig. 3. Mean AAP and aortic nerve activity (ANA) during parabolic flight. Values are means ± SE; n, no. of animals. *P < 0.05 compared with the value at 1 G. **P < 0.01 compared with the value at 2 G.
on ventricle stroke work was less when atrial pressure increased. Thus the effect of 2-G exposure on cardiac performance may be less than that of μG. Further investigations directly and simultaneously measuring stroke volume and peripheral blood flows in addition to arterial pressure in anesthetized rats will be required to understand the mechanisms of arterial pressure changes in response to gravitational changes.

Effect of SAD on Cardiovascular Variables During Acute μG Exposure in Rats

To observe the essential effect of μG on the hemodynamics without main neural control of arterial pressure, all afferents from the arterial baroreceptors were denervated in some animals. However, either during consciousness or under urethane anesthesia, there were no differences of AAP and HR in response to μG exposure between denervated and nerve intact animals. Stress attenuates the baroreceptor reflex (12). The parabolic flight maneuver itself might be stressful for conscious animals, as discussed in Plausible Mechanism of Increased AAP and HR by Acute μG Exposure in Conscious Rats. This may be the reason why changes in AAP and HR in response to μG exposure did not differ between SAD and nerve-intact rats during consciousness.

Similarly, anesthetics attenuate the baroreceptor reflex (1, 34) because we observed no HR changes in response to μG-induced hypotension in nerve-intact animals under anesthesia. Changes in AAP and HR in response to μG exposure, therefore, may not differ between SAD and nerve-intact rats under anesthesia.

Plausible Changes in Arterial Pressure During Spaceflight: New Hypothesis

Because control of arterial pressure is mediated by many neurohumoral factors, which may be time-dependently changeable during prolonged μG exposure, the data obtained by the parabolic flight do not show the chronic effect of μG exposure on the cardiovascular variables. Interestingly, however, in our laboratory’s recent experiment using the space shuttle, it was found that 1) the resting arterial pressure and the pressor response to phenylephrine in anesthetized rats that were raised in space were lower than in control rats raised under 1 G; 2) the number of vascular smooth muscle cells of aorta in rats raised in space was fewer than in the case of control rats; and 3) the number of unmyelinated fibers of aortic nerve, which have a high threshold pressure, was significantly lower in rats raised in space than in control rats (22, 31, 39, 41). It is plausible that these phenomena contribute to low arterial pressure during spaceflight. In fact, although the data of arterial pressure collected in space were very limited, they basically show a decreased arterial pressure during both short- and long-term spaceflights in humans (16, 17). Therefore, we propose the hypothesis that the essential effect of μG on the arterial system discovered in this study is probably one of the factors inducing low arterial pressure during spaceflight.

In conclusion, it has been found that the exposure to acute μG exposure essentially induces decrease of arterial pressure. Considering the similarity of changes in arterial pressure in response to acute μG exposure between the human and the rat, we believe that the measurement of the cardiovascular parameters of the rat during spaceflight will be helpful to understand the mechanisms of cardiovascular deconditioning observed in astronauts after spaceflight (5, 6, 27, 40).

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