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RESEARCH PROGRESS ON THE DEVELOPMENT AND APPLICATION OF ARTIFICIAL GRAVITY FOR SPACE FLIGHT

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Abstract: Faced with the special weightless environment of space exploration, how to effectively ensure the long-term presence of astronauts? stay time The health and safety of problem to solve. This study reviews the development process of artificial gravity by collecting and sorting domestic and foreign literature, and expounds the research on artificial gravity. equipment, methods and their biological effects, and combined with the research work of this research group, the future development direction of artificial gravity is proposed for our country. Provide certain guidance for future deep space exploration.
Keywords: Aerospace medicine; Artificial gravity; Short-arm centrifuge; Countermeasures

1. THE DEVELOPMENT OF ARTIFICIAL GRAVITY

The main task of manned space medical workers is to ensure the health and life safety of astronauts during flight and to create a suitable living and working environment for them. This has always been the first and always necessary solution for manned spaceflight subject. When the spacecraft is in orbit, The astronauts are in a state of weightlessness, while the gravity environments of the moon and Mars are only the gravity of the earth. 1/6 and 3/8. What risks will astronauts face when they stay in these special gravity environments for a long time ? How to take effective medical support measures to reduce the risks is an issue that needs to be solved urgently. This study collects Got it in recent years country Related internal and external literature This paper summarizes the application of artificial gravity as a medical device in aerospace weightlessness and low-gravity environments. Research progress of scientific support technology and its application in future deep space exploration application prospects in China, in order to promote life related to deep space exploration in the future To provide a certain reference for the development of security technology, a summary is now given.

Providing medical support during long-term spaceflight is an important task for the aerospace medical community. Topics of great concern. At present, in order to alleviate weight loss during space flight, The following measures have been taken to achieve adverse effects: physical exercise, lower body weight pressure, penguin suit, water and salt supplement, medicine, etc. [1]. However, these are The protective effect of anti-countermeasures cannot meet the needs of long-term flight. Russian Ross astronauts conducted a long mission During a one- year space flight mission Extensive use of measures such as physical exercise and penguin suits to combat the adverse effects of weightlessness, but it was unable to walk independently after returning to Earth until The situation was relieved after 48 hours. In another aerospace practice, " Peace is empty Interstation of astronauts per The sky is running After exercising on the platform for 2 to 4 hours, the bone density measured by the laboratory after returning to the ground was still lower than the normal level. Physical exercise has improved the astronauts' aerobic capacity, muscle mass and function to a certain extent, but it has no obvious effect on maintaining the astronauts' orthostatic endurance after flight. Not only that, physical exercise has shortcomings such as taking a long time, consuming limited materials and energy in the cabin too quickly, and being monotonous and boring. As a result, astronauts have a negative attitude towards exercise, which affects long-term manned spaceflight. At the end of the 19th century, Olkovs, the pioneer of manned spaceflight It was proposed to use the centrifugal force generated by the rotation of the spacecraft to act as an artificial gravity pair. The idea of anti-gravity effect. In 1952, Germany Chinese scientist Feng · Blau En imagined a space station shaped like a wheel. In his imagination, this This kind of space station can well solve the problem of artificial gravity. 1973 In 2006, an astronaut from the " Skylab " passed the direct path 6.6m running in the test cabin, trying to experience artificial gravity, and finally It also ended in failure.

After millions of years of evolution, humans have fully adapted to the earth 1.0G gravity environment. However, does the human body can only be sustained by gravity What role can we take to maintain the state of adaptation to gravity ? Scientific researchers have proposed 2 methods to achieve artificial gravity in a spacecraft: ① The spacecraft continuously rotates around its own axis, or connects the astronaut ’s cabin with a part of the spacecraft and makes the cabin continuously rotate around an axis change Produce born Leave Heart force, from and Reality now Complete hour sex people work Heavy force; ② Install manned centrifuge equipment in the spacecraft to achieve intermittent artificial gravity through centrifuge rotation. By developing multi -system comprehensive countermeasures such as artificial gravity to reduce or even eliminate the adverse effects of weightlessness, It has attracted the attention of scientists at home and abroad [2-4]. Problems currently to be solved include: how to apply artificial gravity in spaceflight to effectively restore physiological system dysfunction caused by weightlessness; how much strength of artificial gravity is needed; less than the gravity of the ground environment Whether artificial gravity can achieve a counteracting effect;

intermittent artificial gravity is suitable G Values, times and tolerance. Therefore, researchers at home and abroad have carried out comprehensive research work on artificial gravity.

2. ARTIFICIAL GRAVITY RESEARCH EQUIPMENT

The human short-arm centrifuge is currently the main equipment used in artificial gravity research in various countries. The short-arm centrifuge has the following characteristics: less consumables, low cost, easy operation and the ability to provide intermittent artificial gravity, which is very consistent with the actual needs of modern aerospace flight. but, Short arm centrifuge is not Perfect Perfect, by Due to its short rotating arm and fast rotation speed, there are two problems that cannot be ignored: ① Rapid rotation will bring strong discomfort to the human body; ② There is an obvious gravity gradient. When the human head and feet are at different gravity gradient positions of the short-arm centrifuge. Sometimes, people will feel top-heavy or top-heavy. At present, the main types of short arm centrifuges in the world are 2 types: one The first type is a centrifuge with a fixed rotating axis. The human body sits on the seat with the head facing the axis. The heart, the feet are facing outward, and are acted upon by the centrifugal force from head to toe. another Known as the dual bicycle system, astronauts pedal a special bicycle on the inner cylindrical wall of the space capsule. of Bicycle, the special thing about this bicycle It consists of two coupled together, astronaut pedaling bicycles Make it rotate around the cylindrical inner wall, thereby causing damage to the human body produces inertial centrifugal force along the longitudinal axis.

According to drive move square Mode of Difference Different, can Will short arm Leave Heart machine point for Category 3: ① Electrically driven short-arm centrifuge. pass Electric drive the party type operation, with higher speed and larger G value. but due to aerospace Players rotate passively in it, which is prone to major side effects and consumes a lot of electricity. ② Manually driven short arm centrifuge. people move by pedaling The runner drives the centrifuge to rotate. It not only allows astronauts to receive close Similar to the effect of gravity, it can also have the effect of aerobic exercise. It can also be used The human body performs work to produce electrical energy. However, due to the physical limitations of the astronauts, system, in exercise program There are certain limitations in the choice of. ③Electricity and Manual double drive short arm centrifuge. It combines the above two types of centrifuges advantage. This research group Has been developed Got it Electrically driven short arm centrifugal Machine, human driven short arm centrifuge and electric and manual dual drive mode Short arm centrifuge [5], and added a bicycle ergometer to the centrifuge exercise equipment and Performance characteristics and protective effects of type 3 centrifuges The results were compared.

3 ARTIFICIAL GRAVITY RESEARCH METHODS

3. 1 Place Noodle Experiment

Researchers conducted experiments on humans and animals on the ground experiments, the biological effects, protective effects and preliminary forging of artificial gravity were discussed. Refining plan, etc. Research on artificial gravity human experiments carried out on the ground 2 kinds: The first refers to observing the changes in various physiological systems of subjects when exposed to a short-arm centrifuge. This test plan can test the performance of the centrifuge and provide information on changes in the physical and mental health of subjects exposed to intermittent centrifugation. A reliable solution has been developed: ① Determine relevant data of centrifuges that can effectively combat the adverse effects of weightlessness, such as semi- diameter, rotation rate, etc., to compare the practicality of different methods of artificial gravity and the human body's response to different methods of artificial gravity Tolerance level; ② Evaluate the short-term and long-term effects of intermittent otolith stimulation produced by short-arm centrifuge on human cardiovascular function and vestibular function; ③ Comparatively improve the endurance and resistance effects of subjects Short-arm centrifuge exercise program; ④Evaluate the various effects of different body positions on motion sickness, and clarify whether the head is fixed or not in reducing the severity of motion sickness The role of; ⑤ Clarify the impact of circadian rhythm on the effect of artificial gravity countermeasures. The second is to elucidate the changing characteristics of various physiological systems of the human body when exposed to intermittent artificial gravity under simulated weightlessness conditions, such as human head-down bed resting or water immersion experiments. Determine appropriate exposure through short-term and long-term ground simulated weight loss experiments G value, frequency, etc., plot dose-response curves and compare centrifuge bursts Gender differences in human body reactions during exposure, etc., to screen the best artificial gravity exercise program and evaluate the short-term and long-term effects of the artificial gravity program.

So far, the main conclusions of ground artificial gravity research are: ① Most subjects can tolerate a short-term +3.0 Gz centrifuge exposure dew. The gravity gradient generated by the short-arm centrifuge does not have a serious impact on the human body; ② About 1.0G The load is the optimal load; ③ When intermittent artificial gravity acts, there are obvious differences in the responses of various organs and systems of the human body; ④ The artificial gravity research plan involves simulated weightlessness on the ground for not too long, which is harmful to the human body. + There are more studies on changes in Gz endurance, cardiovascular system and vestibular function, but less research on other systems.

very necessary to use animal experiments to explore the role and mechanism of artificial gravity. The animal models commonly used in artificial gravity research include the following: ① Rhesus monkey is a universally recognized primate model, and it also has many advantages in artificial gravity research. Rhesus monkeys walk on two feet, which is consistent with the axis of gravity experienced by humans, and have certain cognitive abilities, which can be used to detect neurovestibular physiology, performance and behavior. In addition, rhesus monkeys are larger, making it easier for experimenters to obtain large amounts of tissue samples and perform physiological tests at the same time. Assessment and analysis of factors and behavioral factors. ②The rat model is the most commonly used and has good adaptability to the effects of centrifuges. Researchers widely use large Mouse tail suspension model, Observe the effects of artificial gravity on cardiovascular, skeletal and muscle Influence on the meat, neurovestibular and immune systems. ③ Mice provide an excellent model for exploring the mechanism of artificial gravity. Mice are small in size, easy to raise, and have strong reproductive capacity. Through genetic processing, researchers can obtain many mouse strains with different genetic characteristics, making the mice very suitable for research needs to explore the mechanisms and transmission pathways. Through transgenes, gene insertion and gene knockout, etc., they can obtain, including gravity Strains with defects in sensory vestibular pathways.

study sheet tomorrow, for a short time every day Standing time to a certain extent Highly resistant to tail-suspension-induced skeletal muscle atrophy in rat hindlimbs. rat bear 1.2G or Anti-effect after the action of 2.6G animal centrifuge It is not obvious, so in terms of preventing muscle atrophy, intermittent artificial gravity action time ratio G value size is more important. Simulating weight loss conditions Under this condition, the response of various physiological systems of the human body to intermittent artificial gravity exists Big difference [6, 7] : Artificial gravity can be significantly reduced 4- week-old tail-suspended rats The degree of atrophy of skeletal muscles of the hind limbs, the longer the exposure time to artificial gravity, the more effective The better the result; the myocardium and vascular tissue are more sensitive to each day + Gx function Very sensitive Feeling, 1h/d standing can to combat simulated weightlessness well no good Impact; 4h/d standing cannot affect Four weeks of simulated weightlessness in rat femur Muscle atrophy provides relief.

3. 2 Space Experiments

Due to the gravity of the earth’s surface existence, the ground is solid The experimental results are not completely consistent with the space experimental results. The use of space experiments to conduct artificial gravity research has irreplaceable The advantages. at 20 century In the 1970s, researchers from the former Soviet Union used " Universe ” Student No. 782 A small centrifuge on board a satellite conducted artificial gravity research. Leave The centrifugal force generated by the rotation of the heart machine is equal to the gravity of the ground. result It shows that the satellite returned after flying for 19.5 days. Back to ground, centrifuge container Inside The growth and development of bacteria, plant seeds and fish eggs are basically not affected to influence. Later in " " Universe " Biological Satellite No. 936 Launch on the star Animal experiments were conducted, 30 large mouse middle of 20 animals were used as control group and only received to the effect of weightlessness, and in addition Put 10 animals into the centrifuge as a confrontation group. subject to artificial gravity. After the satellite enters orbit, the centrifuge generates a force that interacts with the ground's gravity Considerable centrifugal force, in return Back to the past Stop rotating after 2 hours. Researchers It was found that after 18.5 days of satellite flight, the rats on the centrifuge Emergence modern Metabolic disorders, water and electrolyte losses, skeletal muscle atrophy and bone changes were lighter than the control group, which means It shows that 1.0G artificial gravity causes weight loss It has significantly alleviated the adverse effects caused by. In addition, it also issued Some symptoms such as decreased work ability, over-sensitivity of vestibular function and Decreased brain protein metabolism, etc. good shadow sound, the reason may be related to centrifugal The machine has a short rotating arm and fast rotation speed. Later, artificial gravity had a great influence on living things. seeds, bacteria, plant growth shadow Hibiki is also there " Microgravity Laboratory " and " " Neural Lab " flight Observations have been made in China, showing that artificial gravity Confrontation effect.

4 BIOLOGICAL EFFECTS OF ARTIFICIAL GRAVITY

4. 1 Vestibular System

The vestibular system of the human body will be significantly stimulated during the rotation of the short-arm centrifuge. If the compound head movement is also caused by the Coriolis force, it will cause serious illusions. in the past study sheet bright, The human body's movement and coordination functions are significantly reduced when the short-arm centrifuge is exposed. drop. Leave Heart machine change speed and work do able force have Guan, corner speed Exposure to centrifuges with a temperature of ≤3 r/ min has almost no impact on human work ability. The angular velocity is The human body needs to be exposed to a centrifuge of 3~6r/ min 6~8d adaptation period, distance with angular velocity)6r/ min When the scheming is exposed, the vestibular function must be selected good Subjects, special measures such as pre-adaptation training and anti-motion sickness drugs are carried out, but the subjects will still have balance dysfunction. According to reports, The subjects showed adaptation to Coriolis acceleration after intermittent short-arm centrifuge exposure, and the human body's sensory perception and motor coordination remained basically unchanged [8]. Short-arm centrifuge exposure can produce cross-coupling stimulation of the human vestibular semicircular canals, causing delusions and motion sickness symptoms. Research has found that in When exposed to a

centrifuge at 5~20r/ min, the subject 's movement accuracy was negatively correlated with the Coriolis force. A bright environment can significantly shorten the vestibular adaptation period than a dark environment [9]. Progressive training using a short-arm centrifuge can significantly improve subjects' Coriolis acceleration adaptability [10, 11]. This study developed used a short-arm centrifuge and found that the degree of vestibular stimulation was related to the subject's position on the short- arm centrifuge. close sitting position hour Subject By of transport move sick Procedure The degree is more serious [12]. The short-arm centrifuge can induce a variety of vestibular proprioceptive illusions. Confirmed that Coriolis acceleration stimulation through head rotation during short-arm centrifuge training can obviously mentioned high subject Vestibular stability [13-15]. Obtaining artificial gravity through a short-arm centrifuge may also combat the spatial disorientation and positional perception disruption of astronauts during space missions [16]. According to reports, during space flight who receive artificial gravity exercise 4 astronauts are returning After returning to the ground, the otolith-visual reflex reactivity was no longer the same as before the flight. Significant changes occurred, and symptoms of poor orthostatic endurance did not appear [17]. It shows that artificial gravity exercise can maintain the otolith-sympathetic reflex of the human body during flight and help maintain the stability of cardiovascular function during orthostatic stress after flight.

4. 2 Cardiovascular System

Previous studies have shown that in 1.0G and 2.0G Human heart rate and blood pressure changes were similar when exposed to a centrifuge, but 2.0G hour female sex quilt try By of Shu open press Even Low; at 2.0 G and When exposed to a 3.0G centrifuge, the systolic and diastolic blood pressure of the human body changes basically Honichi To, but exist 3.0 G time Heart Rate show With increase Add [18]. 2/d +2.0 Gz, 30 min / time artificial gravity exercise can to confront 4d During head-down position in bed RR interval and its standard deviation, baroreflex sensitivity Sensory and parasympathetic tone changes to maintain cardiovascular autonomy Nervous function is stable [19]. Intermittent artificial gravity can significantly improve Orthostatic endurance and blood pressure variability of the human body during weightlessness, low-frequency power, modified Good autonomic nervous system regulation function [17], Show that artificial gravity can to improve Sympathetic excitability of peripheral resistance vessels helps promote vasoconstriction and prevents blood diversion during orthostatic stress. continuous 3 weeks 30 min / day 1.0~ After 2.5G artificial gravity exercise, the subjects Stroke volume (SV) and heart rate Output (CO) Significant increase in orthostatic endurance time extension of 16%, table Intermittent artificial gravity exercise can improve the body's heart pumping function Able [20, 21].

Artificial gravity combined with exercise can significantly improve the human body's cardiovascular system tube function. This study found that, for 3 consecutive weeks, 30 min /d intermittent After artificial gravity combined with exercise, the subjects' heart rate and heart rate variability Sexual low frequency and high frequency The ratio is significantly lower than before exercise Fall, SV, total peripheral Resistance, left ventricular ejection time, and systolic blood pressure variability low-frequency power were all significant. Increased, indicating that artificial gravity combined with exercise training can enhance cardiac contraction Improved blood pumping function Autonomic nervous function [22, 23]. This research group also Combined with the human head-down bed test conducted further research and Compare Different exercise loads combined with artificial gravity exercise The effect is found in 4 days of head-down bed rest between 1h/d intermittent artificial gravity combined transportation exercise, the subject's SV, CO, orthostatic endurance, exercise endurance and lower Limb vein compliance remained basically unchanged, suggesting combined artificial gravity transport. Physical exercise can effectively combat the cardiovascular function changes during short-term simulated weightlessness. Change [24-27].

4.3 Other Systems

Past research table Ming, centrifugation at +2.0 Gz /d machine exercise Can fight in 1h 4d Caused by lying in bed with head down increase in hematocrit. Artificial gravity combined with physical exercise can effectively stimulate the machine body compensation, improve human heart pumping function [28], and reduce long-term head bowing Neuroendocrinology and immunity of subjects while bedridden System indicators changes [29], the next day 1 session of combined artificial gravity exercise can based on basic Maintain 20 d head Low Bit lie down bed Expect between quilt try By big leg muscle Meat body Product [30]. Iwase et al. [31, 32] mentioned going out Same as G Value Artificial Gravity Combined Exercise may be beneficial in combating cardiovascular dysfunction, muscle meat atrophy and The ideal solution for osteoporosis. They observed that in 20d head down position During bed rest, low G -value artificial gravity combined with high-intensity exercise can Maintain maximum oxygen uptake, pre- Anti-muscle Meat shrinks; while high G Worth artificial weight Strength combined with low-intensity exercise can combat poor orthostatic endurance and inhibit Elevated serum osteoporosis factors. There are studies [33, 34] Report, 1h/d The +2.5 Gz Artificial Gravity Exercise Works Against 21 days in bed with head down During this period, subjects experienced skeletal muscle atrophy and reduced function. This study Study passed 4 days of head-down bed rest and 1 hour/day of intermittent artificial gravity Combined with moderate-intensity exercise, it can effectively combat short-term simulated fatigue. Decreased exercise tolerance caused by weight [35].

5 SUMMARY

in the future of spaceflight, artificial gravity is a potential Multi-system comprehensive protective measures with strong capabilities and application prospects. ground the ground Combining experiments with space experiments to further elucidate the effects of artificial gravity The results and mechanisms of the aerospace weightlessness medical insurance based on artificial gravity are formulated. Barrier technology has certain significance in accelerating the development of my country's aerospace industry.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Sun Xiqing, Jiang Shizhong. Space Medicine and Biological Research. Xi'an: Fourth Military Medical University Press, 2010.

[2] Kreitenberg A, Baldwin KM, Bagian JP, et al. The space cyeliself powered human centrifuge: a proposed countermeasure for prolonged human spaceflight L. Aviat Space Environ Med, 1998, 69 (1): 66-72.

[3] Clement G. Pavy LT A. Centrifugation as a countermca s-ure during actual and sim ulated microgravity: a review. EurJ Appl Physiol. 2004, 92(3): 235-248.

[4] Caiozzo VJ, Haddad F, Lee S, et al.Artificial gravity as acoun termeasurc to microgravity: a pilot study cxam iningthe effects on knee extensor and plantar flexor musclegroups.JAppl Physiol, 2009, 107(1): 39-46.

[5] Sun X Q.Microgravity 一induced cardiovascular decondi-tioning: mechanisms and countermeasure. Chin J Appl Phy siol, 2012, 28(6):532一539.

[6] Sun Biao, Feng Hanzhong, Zhang Lifan, etc. 4h/d standing available Prevent tail hanging for 4 weeks Atrophy of soleus muscle in hanging rats. Aerospace Medicine and Medical Engineering, 2005, 18(1):12-15.

[7] Sun Biao, Liu Chun, Ni Heying, etc. Simulated weightlessness of rats intermittently standing or centrifuging Comparison of effects against skeletal muscle atrophy.Chinese Journal of Aerospace Medicine, 2001, 12(3):140-144.

[8] Brown EL, Hecht H, Young L R. Sensorimotor aspects of high-speed artificial gravity sensory conflict in vestib-ular adaptation. J Vestib Res. 2002, 12(6):271-282.

[9] Dizio P, Lackner J R. Sensorimotor aspects of high -speed artificial gravity: ll. sensorimotor adaptation. JVestib Res, 2002, 12(5):291-299.

[10] Cheung C C, Hecht H, Jarchow T, et al. Threshold-ba sed vestibular adaptation to cross-coupled canalstimulation.J Vestib Res, 2007, 17(4), 171-181.

[11] Elias P Z, J archow T, Young L R.Incrcmen tal adaptationto yaw head turns during 30 RPM centrifugationL.ExpBrain Res, 2008, 189(3):269-277.

[12] Zhang Yu, Yang Changbin, Ren Hujun, etc. Exposure of short-arm centrifuge in different positions Changes in cardiovascular and vestibular functions.Chinese Journal of Aerospace Medicine, 2010, 21(1):30-35.

[13] Song Xinliang, Duan Hong, Sun Xiqing, etc. Short arm centrifuge exposed vestibular error Sleep Inducing effects and characteristics. Aerospace Medicine and Medical Engineering, 2 013, 26(5):359-362.

[14] Song Xinliang, Zhou Yalei, Geng Yan, etc. Observation on the morphological diversity of vestibular proprioceptive illusion induced by short-arm centrifuge. Aerospace Medicine and Medical Engineering, 2014, 27(5):313-317.

[15] Song Xinliang, Huang Ning Xia, Zhou Yalei, etc. For short arm centrifuge Yu Jun Observation on the effects of vestibular acclimation training for pilots. Aerospace Medicine and Medical Engineering, 2015, 28(2):98-101.

[16] Zhu Xiuqing, Jiang Guohua, Liu Yuqing. Factors affecting astronaut disorientation and countermeasures. Journal of Military Sports, 2016, 35(2):1-5.

[17] Moore ST, Diedrich A, Biaggioni I.et al. Artificial gravity: a possible countcrmeasurc for post-flight ortho-static intolerance.Acta Astronaut, 2005, 56(12), 867-876.

[18] Caiozzo V J, Rose G C, Baldwin K Met al.Hemody-namic and mctabolic responscs to hypergravity on a human powered centrifuge. Aviat Space EnvironMed, 2004, 75(2):101-108.

[19] Iwasaki K I, Sasaki T, Hirayanagi K, et al. Usefulness ofdaily +2.0 Gz load as a countermeasure against physiological problems during weightlessness. Acta Astro-naut, 2001, 49(10): 227-235.

[2o] Evans J M, Stenger M B, Moore F B, et al.Centrifugetraining increases presyncopal orthostatic tolerance inambulatory men.Aviat Space Environ Med, 2004, 75(10): 850-858.

[21] Stenger M B, Evans J M, Patwardhan A R, et al. Artifi-cial gravity training improves orthostatic tolerance inambulatory men and women.Acta Astronaut, 2007, 60(4): 267-272.

[22] Zhu Chao, Sun Xiqing, Yao Yongjie, etc. Intermittent short arm centrifuge + Gz exposed Combined exercise for cardiovascular since The influence of main nerve regulation function.Aerospace Medicine and Medical Engineering, 2009, 22(3): 162- 168.

[23] Zhu Chao, Sun Xiqing, Yao Yongjie, et al. 3- week intermittent short-arm centrifuge + Gz exposure and exercise load on human cardiac function able shadow ring. aerospace medicine and Medical Engineering, 2009, 22(2):79-83.

[24] WangY C, YangCB, Wu Y H, et al. Artificialgravity with ergometric exercise as a countermeasure against cardiovasculardeconditioningduring4days ofhead- down bed rest in humans. Eur J Appl Physiol, 2011, 111(9): 2315-2325.
[25] Yang CB, Wang YC, Gao Y, et al. Artificial gravitywith ergometric exercise preserves the cardiac, but notcerebrovascular, functions during 4 days of head-downbed rest.Cytokine, 2011, 56(3), 648-655.
[26] Yao YJ, Zhu Y s, Yang CB, et al. Artificial gravity with ergometric exercise can prevent enhancement of poplite-al vein compliance due to 4-day he ad-down bed rest.Eur J Appl Physiol, 2012, 112(4):1295-1305.
[27] Li XT, Yang CB, Zhu Y s, et al. Moderatc exercisebased on artificial gravity preserves orthostatic tolerance and exercise capacity during short-term head-downbed rest. Physiol Res, 2017, 66 (4): 567 -580.
[28] Zhu Chao v Sun Xiqing, Yao Yongjie, et al. Changes in human heart rate and breathing when combined with short-arm centrifuge ten Gz load and exercise load. Aerospace Medicine and Medical Engineering, 2009, 22(5); 336-340.
[29] Kanikowska D, Sato M.Iwase S.et al.Imm une and neu-roendocrine responses to head-down rest and counter-measures.Aviat Space Environ Med, 2008, 79(12):1091-1095.
[30] Akima H, Katayama K, Sato K, et al.Intensive cycletraining with artificial gravity maintains muscle sizeduring bed rest.Aviat Space Environ Med, 2005, 76(10):923-929.
[31] Iwase S, Takada H, Watanabe Y, et al. Effect of centri-fuge-induced artificial gravity and crgometric exerciseon cardiovascular deconditioning, myatrophy and osteo-porosis induced by a 6 degrees head-down bed rest. J Gravit Physiol, 2004, 11(2);243-244.
[32] Iwasc S.Effectiveness of centrifuge induced artificialgravity with ergomctric exercise as a countermeasureduring simulated microgravity exposure in humansL.Acta Astronaut, 2005, 57(2):75-80.
[33] Symons T B, Moore M S, Chinke s D L, et al.Artificialgravity main tains skeletal muscle protein synthesis during 21 days simulated microgravity.JAppl Physiol, 2009, 107(1):34-38.
[34] Zwart S R, Crawford G E, Gillman P L, et al.Effects of2l days of bed rest, with or without artificial gravity, onnutritional status of humans. J Appl Physiol, 2009, 107(1):54-62.
[35] Li Xiaotao, Gao Yuan, Zhao Jiangdong, etc. Artificial gravity combined with moderate intensity exercise exercise pair Aerobic and anaerobic exercise capacity after 4 days of head-down bed rest shadow ring. Aerospace Medicine and Medical Engineering, 2016, 19(2):95-1 00.