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Mass measurement of the astronauts on the International Space Station (ISS) for nutritional control

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Abstract

The most basic parameter of human nutrition is body weight. For a low-earth orbit space flight environment, body mass has to be measured in some way in weightlessness. Medical requirements for the ISS astronauts include monthly body mass measurements. The Russian-built Body Mass Measurement Device (BMMD) is onboard the International Space Station (ISS) for the purpose. NASA has a research device on the ISS. Both are of older designs, and their value of uncertainty is not documented. Both depend on spring constant, but its nature of decay is unknown. The current technology offers other physical principles for precision mass measurements in space. A combination of a laser interferometer, force or accelerometer sensor would make a precision portable mass measurement device, as ground-tested by Fujii, et al. The large cabin size of the ISS is advantageous in improving measurement uncertainty.

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1. Introduction

Suppose you are to travel into an Earth orbit. After your flight safety has been secured by ensuring proper vehicle design and a flight plan, you must consider Environment Control and a Life Support System (ECLSS). ECLSS supplies you with atmosphere and a water supply. On the International Space Station (ISS), water is launched from the ground. Then water is used for drinking as well as submitted for electronic decomposition into oxygen and hydrogen. Oxygen is for breathing, while hydrogen is dumped

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outside the ISS. Most of the water, i.e. either condensation on the wall or urine, is re-circulated by a water regeneration system to be reused for oxygen generation or drinking.

The next supply you need is food (Fig. 1), for which the right mix of nutrient components is necessary. The physiologically necessary nutrient ingredient requirement for the ISS is based on a WHO document [1].

Fig. 1. Dining on the International Space Station (ISS). JAXA photo 50P2011000862, Nov. 2011

2. Energy intake by astronauts

The issue of supplying the right amount of energy, or calories, to space flyers by oral intake has been a topic of discussion for the last 40 years and is still debated by space medicine experts [2-3]. Since orbital vehicles are under microgravity, ‘body mass’ is the term used for the ground equivalent term of ‘body weight’. The calorie intake required is calculated using the same method used for hospital meal calorie calculation. For the ISS United States Orbital System (USOS), the United States standard is the basis for this calorie estimation. The current ISS food requirement for the U.S., Japan, Europe, and Canada is prepared according to a NASA document [4], while each partner also supplements the cyclic main menu with their particular items (Fig. 2). The physiological variables for energy consumption are: individual body surface area (estimated by height and weight), level of activity (hard labor, light desk work, or recumbent and bedridden), gender and age. For example, a 35 year-old, 65 kg, 172 cm high male engaged in heavy work balances the energy consumed with a daily intake of 3,490 kcal (14,580 kJ) [1, Table 11]. Typically, male astronauts need more than 3,000 kcal/day to retain their pre-flight body mass. As they do not feel hunger themselves, physicians on the ground (Flight Surgeons) encourage them to eat properly, based on their estimated energy intake via a weekly questionnaire.

Fig. 2. ISS food containers store plastic bags for space food. JAXA photo 50P2011000860, Nov. 2011
If astronauts are not given any instruction concerning energy intake in terms of food, they tend to lose weight while in orbit. The cause of this behavior is unclear. There are theories based on the body fluid cephalic shift due to microgravity (in light of human physiology, the ISS environment is weightless), change in taste, and others [2]. One possible factor is that without a food refrigerator (the ISS has none, Skylab had one), fresh food is lacking in appeal (Fig. 3). As we still do not understand the physiology of this body mass loss, for now, our goal is for astronauts to retain their pre-flight body weight. In this sense, “Calories are good for space flight.” The physiological study of astronaut nutrition remains an active research topic, e.g. ‘Nutritional Status Assessment’ experiment by NASA (Fig. 4).

In addition to nutrient modification for space food, the authors propose Radio Frequency IDentification (RFID) technology to make intelligent food packages that contribute to food inventory monitoring [5] (Fig. 5).

Fig. 3. On the ISS, the supply of fresh food is very limited. JAXA astronaut Satoshi Furukawa, M.D. with a precious fresh apple. JAXA photo 50P2011000830, 3 Nov., 2011

Fig. 4. Nutritional Status Assessment experiment blood draw on the ISS. JAXA photo 50P2011000853, Nov. 2011

Fig. 5. Food package seal monitor by two RFID (Radio Frequency IDentification) IC tags. One of the two antennae will be sheared off when the seal of the package is broken. This can be used to monitor package usage
Onboard exercise requires energy

Although orbital body movement is easier than on the ground, astronauts are instructed to follow physical countermeasure protocol to overcome the adverse effects of microgravity, which includes 1.5 hours of exercise (plus 0.5 hour of preparation and stowing) on the ISS. Exercise machines include a treadmill (running on a metal belt), cycle ergometer (bicycle), and a resistive exercise device (similar to rowing and weight lifting movement) (Fig. 6). The energy that exercise requires is more than that of heavy work. For example, treadmill exercise at a speed of 10km/h consumes about 700 kcal/h on the ground.


3. Body Mass Measurement Device

While food supply options exist, there is only one method to measure whether an astronaut has consumed the right amount of food, i.e. calories, namely the body mass of the astronaut. So, how can we measure body mass under microgravity?

There is no body weight, but body mass on the ISS

Apparently, under microgravity, some ground methods used to measure body weight do not work. The mass of the human body is the property that can be measured on space vehicles in low earth orbit. Usually body weight, as a physical property, is not defined in orbit. Balance and load cells are excluded from orbital/interplanetary use, unless an artificial gravity field is generated, either by a human centrifuge [6] or a linear elevator (‘drop tower in space’) [7-8]. Currently, for the ISS, a spring-mass oscillation system by the Russians [10-11] (Fig. 7), and a spring-displacement system by NASA [7] (Fig 8) are in use. The former is said to have sufficient precision to follow the body mass trend of the astronauts onboard. Skylab and Space Shuttle used a spring-mass system [7, 9].

The authors propose laser interferometry and a force transducer method with body linear translation (Space Scale) (Fig. 9) [8, 12-17] as a near future Body Mass Measurement Device (BMMD). With parabolic flight data on jet planes, its data uncertainty is predicted to be better than conventional methods.
The stability of body movement during human body translation for more than 3m was demonstrated on the ISS.

Fig. 7. Russian spring-mass ISS BMMD for MO-8 body mass procedure. JAXA photo 50P2011000633, 28 Sept. 2011

Fig. 8. SLAMMD spring-displacement ISS BMMD by NASA. JAXA photo 50P2011000720, 5 Oct. 2011

**Body mass measurement on the Moon and Mars**

On the Moon and Mars, BMMDs similar for ground use can be applied, although the surface acceleration is smaller than on Earth. The far smaller acceleration field generated by a space station linear acceleration platform is proposed by Thornton as a ‘Space Drop Tower’ [7-8].

**Small mass measurement under microgravity**

For the small mass of experiment samples, a centrifugal force system [18], Levitation Mass Method [19] (Space Balance) by Fujii, force transducer collision method by Maru and the authors [20], etc. are proposed.
Fig. 9. Space Scale scheme. Its principle is significant displacement, for precision, measured by laser interferometry, with a force transducer. Desktop and parabolic flight models were tested and evaluated for this principle.

4. Summary

As virtually the sole indicator of astronaut nutrient status monitor, body mass measurement is an important tool for ISS medical operations. However, there remains considerable scope for further research and eventual replacement of the current BMMDs onboard the practical implementation of Body Mass Measurement Devices (BMMD). The authors propose ‘Space Scale’ as an ISS BMMD in the near future.

References