24 – Artificial Gravity

SUMMARY

Reduced gravity causes different problems with different organ systems requiring different levels of artificial gravity and exercise regimens. An indoor centrifuge is designed into certain habitats to help extend crew stay and to use to determine the artificial gravity prescription (AGRx) for healthy gestation and childhood. The centrifuge doesn't need to be huge so long as crew don't move their heads while inside and spinning.

OVERVIEW

There are legitimate concerns about whether lunar gravity is sufficient for health for those staying on the Moon for an extended time. Intermittent artificial gravity, by spending time in an indoor centrifuge, could help mitigate the effects of reduced gravity. But we need to conduct animal experiments to determine how much artificial gravity will likely be needed. Studies in a centrifuge on the Moon will probably be the earliest way to determine the amount needed.

QUICK DEFINITIONS

For those readers not particularly familiar with artificial gravity, here's a few acronyms / terms:

- **AG:** Artificial gravity
- **Spin gravity:** Achieving artificial gravity by spinning around such as in a centrifuge.
- **AGRx:** The artificial gravity prescription meaning how much spin gravity exposure is needed to have acceptable health outcomes.
- **Gee:** Meaning Earth's gravity level. 1.0 gee is what we experience standing on Earth. 0 gee is what astronauts experience in orbit. The Moon has 0.16 gee.
- **Microgravity:** The gravity level experienced in orbit. It isn't exactly 0 gee, but it is very close.

THE PROBLEM: HEALTH CONSEQUENCES

We are concerned with the significant effects of reduced gravity on several different organ systems, and each will need different amounts of artificial gravity to treat.

Nervous System (Balance & Circulatory)

Upon arrival in orbit, within a day or two, an astronaut's inner ear will adjust away from Earth orientation to that of microgravity. Upon return to Earth, it takes another couple of days to regain one's "Earth legs". So, this isn't a big problem.

Videos showing returned astronauts being carried away from their landed capsule so many people presume that this means that their lack of exposure to gravity has made them so weak that they cannot stand up and support their weight. This is incorrect. Astronaut Scott Kelley was able to stand up and walk almost immediately after being removed from his capsule after a lengthy stay on the ISS. In the video compilation of him after his flight, it shows him over the next 24 hours having improved balance.

The point is, the coordination of balance is something that recovers very quickly without intervention. Nothing in particular needs to be done about it. And on the Moon, there will always be a down direction. So, it may not be a problem at all.

Similarly, when astronauts spend time in reduced gravity, when they return to Earth, gravity starts pulling their blood away from their head to their legs leading to fainting. Not as with their balance system, the nervous system learns quickly to maintain blood pressure in the brain. Constructive leggings and salt supplements can help during the few days of transition.

Muscular System

Loss of muscle mass is common among astronauts in orbit. But given the exercise equipment that NASA had shipped to the ISS it has largely solved this problem. Indeed, some astronauts have returned with greater muscle mass than they went up with. So again, this doesn't need much in the way of an artificial gravity prescription.

Now we start to get into some organ systems that will likely need artificial gravity.

Skeletal System

It is generally known that astronauts who are in orbit start losing minerals (e.g. calcium) from their bones. In fact, it is said that they lose about 1% of their bone mineral density (BMD) each month. For a 6-month mission on the ISS, it's probably acceptable. But beyond six months, it would start to add up.

A 2020 study by Mortreaux involved partial weight bearing by partially suspending the pelvis of rats to offload forces to Martian levels. The result was the loss of bone mineral density over the two-week study period. I take is as evidence that we may well have skeletal BMD loss over time on Mars needing a regular impact exercise program to prevent that loss.

But as with the muscular system, NASA's fitness equipment on the ISS has shown to largely stop bone mineral density loss. So, using some combination of impact exercise, heel strike equipment, weighted clothing, and possibly medication, BMD loss would be able to be controlled.

Hydrostatic Effects

Here's the real problem. We have fluids in our tissues. It's not just the blood within our arteries and veins. Our arteries can constrict and regulate our blood pressure. But it is the headward shift of fluids that is the problem thereby increasing the pressure in our brains and eyes. The medical term for this is Spaceflight-Associated Neuro-ocular Syndrome (SANS).

There has even been one recorded case of blood clot formation in the neck of an astronaut on the ISS due to the stagnation of venous blood. The concern is that the blood clot could break off and travel to the lungs causing pulmonary embolus, a potentially life-threatening condition.

Exercises won't help. Rather, the hydrostatic fluid needs to be drained away from the cranium to the lower extremities. This can be done in one of two ways. The Russians' chosen method are negative pressure trousers. This works but only while wearing them. Rather a centrifuge is what is needed.

The Centrifuge

This book proposes that a centrifuge be included in lunar habitat designs for two reasons:

- To improve adult crew health and hence to extend crew stay.
- For animal studies to determine how much artificial gravity is needed for healthy gestation and childhood.

However, it is recognized that centrifuges on the Moon or Mars cannot be made half a kilometer in diameter. It is also clear that it is impractical to create a circular train track half a kilometer in diameter nor would it be practical to raise children in shielded train cars going around said track.

Rather, the best that we can do would be to create spinning centrifuge rooms no bigger than the diameter of the largest specially hab (i.e. 90 m diameter).

The Coriolis Effects

The problem with these intermediate length centrifuges is that, for the crew to get a full gee, they will need to spin around faster than the four to six gees that crew can adjust to. Turning their heads while being spun around can induce powerful forces within the semicircular canals in the inner ear instantly creating dizziness and nausea -- not good. But so long as one does not turn their head, there are no Coriolis effects.

In 2016, I and two other space advocates went to our local theme park and had them spin us up to 11 RPMs (full gee at 15 m diameter). Our goal was to conduct up to 10 sedentary activities in the 15 minutes that the operators gave us. We were able to easily conduct all the sedentary activities except for falling asleep (15 minutes wasn't enough time). To us, this proved that one didn't need to have one's head strapped down to avoid the Coriolis effects in an intermediate-length centrifuge.

People will, understandably, often suggest that impact exercise could be done within the centrifuge. Now this idea doesn't work. Any impact exercise inevitably causes one to bounce, inducing a linear acceleration resulting in a Coriolis effect. Alternately they suggest that crew can get eight hours a day of artificial gravity by sleeping in the centrifuge. Again, it is an understandable suggest but it is again incorrect. The hydrostatic pressure distribution has to do with the difference in pressure between the head and the food. Think about if the pressure increases and you swim to the bottom of a swimming pool. When you lay down, the height of the fluid column in your body is no longer very tall -- maybe 30 cm at most. So, the pressure difference will not be very much. The pressure in your cranium will be about the same as in your toes. True, one could sleep tilted up in one of those inclined, seat beds. But it isn't the same as standing and standing while sleeping isn't practical. We want to be lying flat if we are to get a good night's sleep.

Immune System

It has been noted that the immune system is affected by reduced gravity. Unfortunately, there is not enough information to determine how much of a problem this is if at all. Given the mineral changes from the turnover effects on the long bones, perhaps better bone health from exercise will help. We'll have to conduct animal studies to find out.

ARTIFICIAL GRAVITY AND REPRODUCTION

Not everyone moving beyond Earth will want to reproduce. But some will. And there's something good about retirees seeing children running around. We want that.

But (serious question here) will it be safe to do so?

How Healthy is Healthy Enough?

Our bodies are healthiest when they are upright, in full gravity, and active. But is it considered unethical if we don't live up to that standard? Let's say that parents purchase an Xbox for Christmas for their child and, as a result, their child becomes a lot more sedentary due to my game playing all day long. Do we consider that a form of child abuse and throw their parents into jail? No, of course not. Being a reasonable society, we consider that it is not advisable but acceptable none-the-less. So, we can live with some level of unhealthy and still consider ourselves to be unacceptable.

A child spending excessive amounts of time playing video games can become unhealthy, but they are still able to reproduce. We should not fundamentally conclude that, just because settlers are spending some of their time outside of a centrifuge then, necessarily, they won't be able to reproduce.

THE ARTIFICIAL GRAVITY PRESCRIPTION

What we need to do then is to find out how much artificial gravity is needed to be healthy enough. It would be unethical to just wait, have someone get pregnant and just see what happens (aka "Learning on the job"). Rather, we need a set of animal studies.

Components of the AGRxs

Most space advocates have the mistaken view that the AGRx is some specific number between 0 gee and full gee above which reproduction is possible and healthy. However, one can achieve full gee in an indoor centrifuge and, so long as one holds one's head still, no Coriolis effects are induced. Since one can therefore get a full gee in a centrifuge, the variable to be determined is just how many hours of full gee are required for healthy gestation, childhood, and adulthood.

This is a practical question because, if one needs an hour in the morning and an hour in the evening to "drain" fluids from the skull (for example), then this is doable since we spend about 10 hours a day doing sedentary activities. But if one needs to be in a centrifuge 24/7 to survive long-term then this is not practical.

So, the true AGRx is not a single number between 0 and 1 but rather the number of hours one needs to spend in a centrifuge to be healthy enough. It is the total amount of intermittent full AG that is needed for sufficient health.

When Do We Need to Know the AGRx?

Is there a point in time that we need to figure out the AGRx for healthy gestation. Yes, there is.

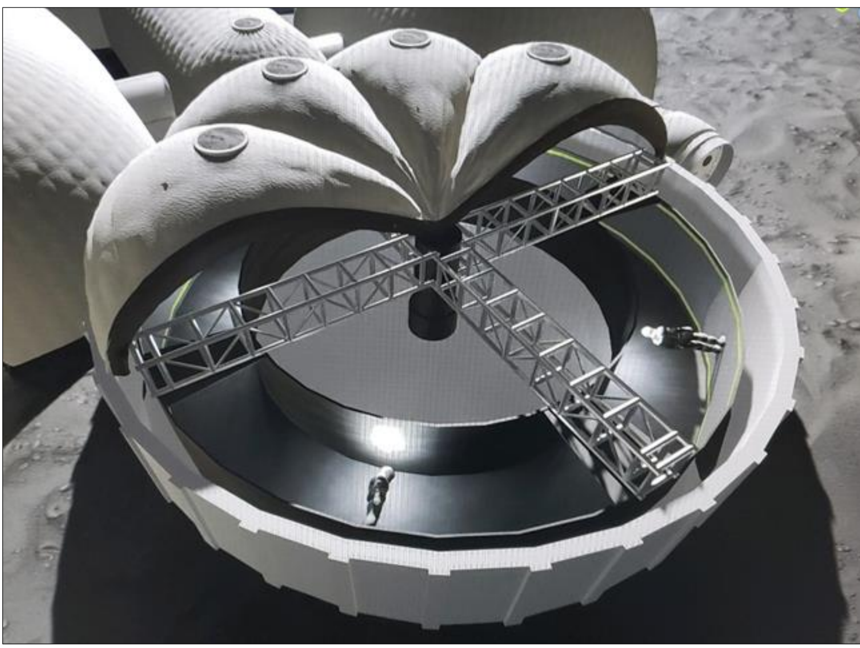
If a woman gets pregnant while on a tourist trip in LEO (something that is likely to happen in time) she can quickly come down to Earth and live out the rest of her pregnancy in Earth's full gee. The same is roughly true with a woman on the Moon who gets pregnant.

But, after a fleet of Starship concludes its trans-Mars injection burn (TMI) there's no coming back. And once a woman gets pregnant on Mars, it would take too long for the planets to line up and then spend six months on the way back. That pregnancy has a good chance of going full term. We need to have the results of the animal studies in hand to infirm that pregnant woman as best we can about how much artificial gravity she needs to have a healthy baby.

That point in time comes when enough people (i.e. more than 500 professional astronauts) have headed to Mars. Based upon Starship development progress, Raptor 3 engine production rate, Starship body production rate, and remaining development hurdles, I would place that date as no earlier than early 2035. As of this writing, that is 9 years away. And I believe that this amount of time is sufficient, but we had better not wait too long to get started on those studies.

In the meanwhile, we should avoid pregnancy among the crew. Based upon our experience with professional astronauts on the ISS, I believe that an unexpected pregnancy will likely be avoided up to the first 250 astronauts (about 2033). But, especially as couples go or crew start firming romantic relationships, we get into a danger zone where it becomes just a matter of time before an unwanted pregnancy occurs. For married couples such as among the Initial Permanent Crew on the Moon, I recommend that the men have vasectomies (highly effective, provable, and mostly reversible) and gave gametes stored back on Earth to ensure they reproduction always remains an option. Yes, it's an awkward topic but necessary.

THE CENTRIFUGE DESIGN



A centrifuge is included in the StarHab, the InstaBase, and in an AG specialty hab called the SpinHab in the International Lunar Base. This design inclusion reflects the importance of artificial gravity to extend crew

Biomedical Indicators:

In order to accurately determine the health impact of reduced gravity exposure, we need to identify measurable biomedical indicators such as: bone marrow density, muscle strength, intracranial pressure, intraocular pressure, blood pressure, density, & viscosity, pressure, immune markers, back pain, presence of venous thrombosis, fetal activity, birth weight & growth curves, and probably others. Deciding what difference is acceptable may be a judgement call.


Middle Articles

Structure of the Scientific Paper

www.DevelopSpace.info/extended

Proposed Protocol for Determining the AGRxs

Given the relatively near-term risk of a woman getting pregnant on Mars, it is proposed that the AGRxs be determined as quickly as possible. To that end, an outline of a protocol is here described while experts are needed to develop a more accurate protocol.

Start with many pregnant laboratory mice, assigning several to different hours of full AG. The length of pregnancy for a laboratory mouse is three to four weeks. After assessing the biomedical indicators, we home in on what appears to be a healthy level of full AG. Next, we increase the number of mice subjects above and below this level and conduct another month's experiment with more pregnant mice while raising the first mice pups in a spectrum of full AG to determine the AGRx for healthy childhood.

Just as soon as one is beginning to develop confidence in the AGRx for mice then one can simultaneously start on studies to determine the AGRx for the next level of animal model. The starting hours of AG for the second animal model will be somewhat below to somewhat above that found for the mice. The next level after large numbers of mice could be either hamster (3 weeks) or rabbit (4 weeks). A similar approach would be used for them as was used on the mice.

Just as soon as one is beginning to develop the AGRx for the second animal model then we begin the AG Rx protocol on the first primate, the marmoset. These have a gestation period of about 4.7 months. Once again, it may take two or three rounds of studies on pregnant marmosets before moving on to the last animal model.

The last model is the macaque monkey. We would prefer to do the study on chimpanzee, but these are excluded from study in the United States. The macaque monkey has a pregnancy length of 5.5 months. After about three rounds of pregnancies, we would have our best idea of the AGRx for humans.

If we add these lengths of time together, we get: (1 mo. x 3 + 1 mo. x 3 + 4.7 mo. x 3 + 5.5 mo. x 3 = 3 years). If the first permanent base is established on the Moon in 2028, then three years after that would bring us to two years before the hypothetical 2033 date when the first Martian pregnancy might occur. This just goes to show just how much we need the centrifuge in the lunar base and how urgent it is that we be ready to seek the AGRx just as soon as the first permanent crew inhabits the first lunar habitat(s).

Making the Decision for the First Off-Earth Pregnancy

The first full gestation of a human baby off Earth should not be taken lightly. But attempting to delay the first off-Earth pregnancy could backfire in terms of the ethical outcomes. In particular, it may be best to intentionally have the first off-Earth baby be conceived on the Moon where careful monitoring could allow early detection of a problem with immediate return to Earth. In this way Martian residents could be better informed to take precautions to avoid pregnancy.

Who should decide whether to become pregnant and remain on the Moon? We will have done what we can to make the decision for pregnancy as well informed as we can given the limited time. Whether or not to become pregnant and remain on the Moon is a very personal decision that we leave up to the parents. They can be advised by experts but ultimately it comes down to those who have the most responsibility for the baby – their parents.

The Significance of the First Off-Earth Baby

Humanity is about to start moving beyond Earth. The first child born off Earth will go down in history as the first of those humans for whom Earth is not their home, but they are from “out there”. We need to work to ensure that this first off-Earth human gets off to a good start and determining the AG Rx is the essential step to ensuring this.