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A Novel Sole Design for Astronaut to Stimulate Lower Body Blood Circulation

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Abstract – "Gravity" is a habit that is hard to shake off. This is well-realized by astronauts during their long stay in space, Since there is no gravity to pull blood to lower parts of the body within 2-3 months astronauts have puffy faces and bulging blood vessels in their necks and appearance isn't the only ugly side effect of microgravity. The lack of blood flowing to and from the brain can cause astronauts to feel dizzy and sometimes even faint when they return to Earth's gravity. Microgravity has also caused small blood clots in two astronauts which could have been fatal. To prevent this we came up with our solution "Bubble For Foot Trouble" . It is a carefully designed Shoe with a custom sole that ingeniously solves the problem of blood flow. It works on a basic principle of "acupressure", We have used acupressure points here for the circulation of blood and roller for the friction. Astronauts don't have a forceful walk in the shuttle, they float and more importantly use their feet for attaching themselves to foot rail. Once astronauts apply force on their feet or move through the foot rail in the ISS (international space station) their heel or toe is pressed and the attached mechanism consisting of leaf spring and gear train will generate the rotation of the roller through the rack & pinion gear thus stimulating the blood circulation.

Keywords **– acupressure, lower limb blood circulation, microgravity, and microcirculation**

I. INTRODUCTION

Our bodies aren't built for space, they're built for a planet a lot like our own. Human beings have evolved here on Earth over millennia, so our bodies have adapted to excel in a gravity environment under the protection of our planet's atmosphere. In low Earth orbit, however, those ubiquitous elements are taken away, and the body's various systems adapt accordingly. With the advent of space stations that can be inhabited for long periods of time, exposure to weightlessness has been demonstrated to have some deleterious effects on human health.

The environment of the International Space Station isn't exactly hospitable to the human body. Humans are well-adapted to the physical conditions at the surface of the Earth. The most common problem experienced by humans in the initial hours of weightlessness is known as space adaptation syndrome or SAS, commonly referred to as space sickness. The first case of SAS was reported by cosmonaut Gherman Titov in 1961. Since then, roughly some 45% to 75% of all people who have flown in space have suffered from this condition. Symptoms of SAS include nausea and vomiting, vertigo, headaches, lethargy, and overall malaise. Thanks to microgravity, In response to an extended period of weightlessness, various physiological systems begin to change and atrophy. while living in space some of which they can counteract through daily exercise and other activities. But the space environment also exposes astronauts to other elements that cannot necessarily be mitigated.

Perhaps the biggest change astronauts experience is bone and muscle loss. Humans on Earth work out these systems every day, simply by moving and standing against gravity. But without gravity to work against, the bones lose mineral density and the muscles risk atrophying. These effects can be minimized through a regimen of exercise. To prevent some of the effects associated with weightlessness, a treadmill with vibration isolation and stabilization designed for the International Space Station (ISS) was first evaluated during STS-81.

Fig. 1. Astronaut running on treadmill.

Three crew members ran and walked on the device, which floats freely in the micro-gravity experienced during orbit. For the majority of the more than 2 hours of locomotion studied, the treadmill operated well, and vibration transmitted to the vehicle was within the micro-gravity 'allocation limits that are defined for the ISS. The treadmills are intended to help astronauts stay fit, fighting off the bone loss (spaceflight osteopenia) and muscle decay that otherwise comes with space travel. Astronauts use bungee cords to strap themselves to the treadmill in order to remain in contact with the equipment while in microgravity. Other significant effects include fluid redistribution, a slowing of the cardiovascular system, decreased production of red blood cells, balance disorders, and a weakening of the immune system. Lesser symptoms include loss of body mass, nasal congestion, sleep disturbance and excess flatulence. In an interview with NASA Astronaut Scott kelly he stated: After about 2 months in orbit your feet molt and like some reptilian creature skin on the bottom of your foot sheds, leaving soft pink flesh in its flesh in its place".

Fig .2. Astronaut scott kelly demonstrating skin peeling in space .

he wrote Crewmembers also experience a disruption in their proprioceptive system, which tells where arms, legs and other parts of the body are oriented relative to each other. "The first night in space when I was drifting off to sleep," one Apollo astronaut said in a NASA interview, "I suddenly realized that I had lost track of my arms and legs. For all my mind could tell, my limbs were not there."Astronauts face many hazards in space that can do strange things to the human body. Gravity changes, exposure to radiation and confinement all take a toll on bodies that are used to being protected by Earth's atmosphere, scientists say that Just like on Earth, there is a robust population of bacteria and fungi on the International Space Station (ISS) - and a new study catalogues its exact composition.

Most of the microbes are associated with humans, particularly the bacteria Staphylococcus (26% of total bacteria isolated), Pantoea (23%) and Bacillus (11%), according to a statement on the new work. Other organisms come from specific parts of humans, such as Staphylococcus aureus (10%), which is usually found in human nasal passages and skin. Another example is Enterobacter, whose percentage was not specified in the release, which is found in the human gastrointestinal tract. While it sounds like a gross combination, the scientists noted in the statement that similar bacteria are found in mundane Earth environments such as offices, gyms and hospitals, so the space station is similar to these other "built environments" frequented by humans. Physiological Effects of longer stay in space :

1.You Grow Taller

During the six months that most astronauts spend on the International Space Station, they can grow up to 3 percent taller. Without gravity, the spine is free to expand, making the space flyers taller, even when they first return to Earth. The astronauts return to their preflight height after a few months of being back within the planet's gravity.

2. Muscle Mass Meltdown

In the weightlessness of space, muscles aren't needed to support the body. An astronaut's muscles start to adapt to that change almost immediately. Instead of maintaining the usual base of muscle mass needed for life on Earth, astronauts' bodies quickly get to work ridding themselves of unnecessary tissue.

Although this might be ideal in space, it's problematic once back on Earth. Astronauts have to exercise for two hours a day on the space station just to maintain a healthy amount of muscle mass that they will need once they are back on the planet.

3. Bone Density Loss

All that exercise on the space station also helps prevent bone-density loss. Each month, astronauts could lose up to 1 percent of their bone density if they don't get enough exercise.There are two treadmills and two stationary bicycles on board the space station to help the residents keep in shape during their time in orbit.

4. Sleep disturbances

Astronauts have reported seeing flashes of light zap through their eyes as they try to rest, making it difficult for them to sleep on the space station. The flashes are actually from cosmic rays high-energy particles that beam through the solar system shooting through the orbiting outpost. Spaceflyers have described the flashes as "fireworks" or "streaks." Although the radiation from the cosmic rays can build up over time, the particles don't pose too much of a risk during the limited time that astronauts spend on the station.

5. Coordination Conundrum After Landing

After coming home from a stint on the space station, many astronauts have reported difficulty adjusting back to gravity. Sometimes, spaceflyers will drop things, forgetting that gravity is influential back on Earth. After six months in microgravity conditions, it is difficult to adjust to life in a place where materials fall if you drop them.

6. Blood circulation in space:

Astronauts have to be in top physical condition and must meet specific health requirements, such as having good vision and normal blood pressure. In microgravity, body fluids are moved around. Fluids such as plasma are lost throughout the body. Plasma is where red blood cells live. Less plasma means there is less blood to carry oxygen to the rest of the body. On Earth, the blood pressure in our feet is nearly three times higher than it is in our head. In orbit, however, this difference disappears, and blood pressure is maintained normally throughout the body.

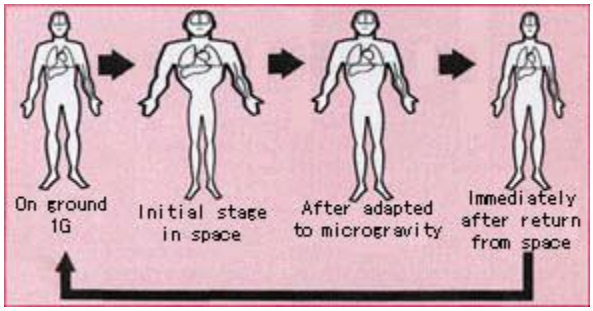

Fig.3.Blood pressure adaptability of body in space and gravity.

In space, there's a much different result. There's no gravity to pull blood into the lower part of the body. Instead, blood goes to the chest and head, causing astronauts to have puffy faces and bulging blood vessels in their necks. And appearance isn't the only ugly side effect. The lack of blood flowing to and from the brain can cause astronauts to feel dizzy and sometimes even faint when they return to Earth's gravity.


Fig.4. NASA Astronaut Peggy Whitson on Earth (left) and with noticeable puffiness in space (right) Credit: NASA.

That's why a new experiment on board the International Space Station called Cardiovascular and Cerebrovascular Control on Return from ISS (CCISS) is examining how long-duration exposure to microgravity affects crew members' heart functions, blood pressure and blood vessels that supply the brain. Being in microgravity can have strange effects on the body now it has emerged that it can make people's blood flow backwards. The changes to circulation caused two astronauts to develop small blood clots, which could have been fatal. Fortunately, though, the man and woman affected came to no harm. The blood changes happened in a vessel called the left internal jugular vein, one of two that normally move blood out of the head when we are lying down. When we are upright, they mostly collapse to stop too much blood from draining out of the head, with our circulation taking a different route through veins with more resistance instead.

Acupressure stimulation for improving blood circulation:

Acupressure is a specific type of massage that relies on applying pressure to various points on the body. Acupressure massage is a natural holistic technique to address blockages that may be causing additional health problems. Including in the flow of blood circulation acupressure Acupressure originated in ancient China. In acupressure, muscular tension is released by applying pressure with hand at specific acupoints or pressure of the thumbs on specific points or the application of pressure to acupoints is used to balance the flow of the physiological energy. Acupressure has been practiced as a healing art for at least 5,000 years. It is the third most popular method for treating pain and illness in the world. This complete health system has been documented for use in treating over 3000 conditions. Besides being an ancient healing art to relieve muscular pain and/or tension. Acupressure Therapy helps the body functions optimum capacity, which results in more energy, greater vitality, better emotions and mental health, all by applying physical pressure on different points on the surface of the body to bring about relief through greater balance and circulation of fluids (blood, lymph) and metabolic energies in the body (heat, Qi). Thanks to it's natural anti-inflammatory,muscle-relaxing and pain relieving properties

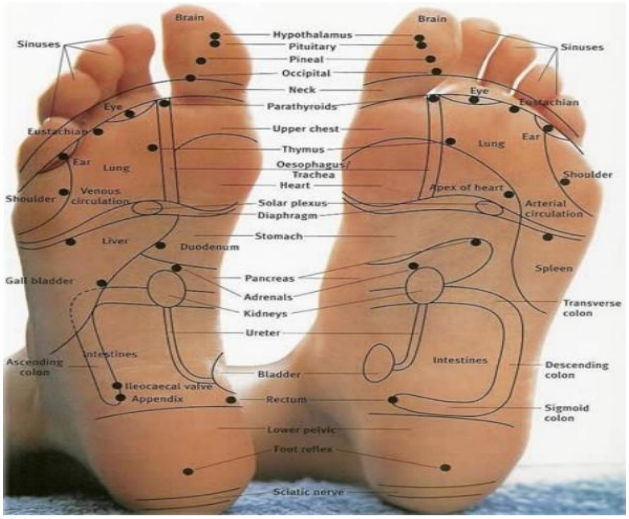

Fig .5. Acupressure points on feet for stimulation .

Acupressure excites receptors or nerve fibres in the stimulated tissue which are also physiologically activated by strong muscle contractions and the effects on certain organ functions are similar to those obtained by protracted

exercise. Both exercise and acupressure produce rhythmic discharges in nerve fibres, and cause the release of endogenous opioids and oxytocin essential to the induction of functional changes in different organ systems. acupressure has been accepted for pain relief in most countries and is commonly used in general practice and pain clinics as a complement to conventional treatment. heart diseases have been treated with transcutaneous nerve stimulation or acupressure. Richter et al compared the effects of acupressure and placebo in 21 patients with acute and stable angina pectoris. Treatment was given thrice weekly for 4 weeks. The number of pain attacks decreased studies demonstrate an immediate short-lasting effect following acupressure but there is evidence that a longer-lasting effect is possible. acupressure induces in many patients an increased sense of well-being, calmness and improved sleep.

II. LITERATURE REVIEW

The NASA'S ground based studies of the headward fluids shifts related to space flights show that the loss of hydrostatic (gravitational) pressures in microgravity shifts blood ,spinal fluids and tissue fluids towards the head, causing venous congestion and leading symptoms compatible with increased intracranial pressure (ICP). Simulation of gravitational stress by application of lower body negative pressure (LBNP) is proposed as a means to reduce ICP and reestablish cerebral health in astronauts during long mission stays in space. LNBP shifts blood and other fluids from the head and neck to the lower body [1].

By the analysis of human microcirculation in weightlessness. microcirculation consists of a network of blood vessels of the smallest scale, microcirculation is essential for tissue oxygenation, organ perfusion, gas metabolism and exchange of nutrients and waste products]. Accordingly, malfunctioning of the microcirculation might cause organ-dysfunctions leading to possible life-threatening dysregulations[2]

Treatment of Rosacea using acupuncture for improving the local skin microcirculation discovered thier patients experiencing significant improvements in the region around the nose after 3 sessions of acupuncture treatment. They think acupuncture may be effective in treating rosacea through redistributing micro-circulation of blood at the localized area of effect. This result suggested that the acupuncture treatment might be effective in treating rosacea through blood redistribution and micro-circulation of local skin area.[3]

Xiangfeng Li et, al studied the effect of acupressure stimulation for increasing the blood flow in lower limbs in patients suffering peripheral arterial occlusive diseases. Group of 30 patients with stage 2 peripheral arterial occlusive diseases (PAOD) underwent blood flow measurement before acupressure stimulation. The measurement of blood flow was determined by transcutaneous oximetry (tcPO2) monitor.
To find out whether the blood flow of the lower limbs that had undergone an ipsilateral sympathectomy increased, the tcPO2 values at all sites of these lower limbs were summarized together. The mean values at the distal crus and dorsum of the foot before and during stimulation were 44 ± 16 mmHg and 46 ± 14 mmHg (n = 20) moreover, all patients felt relaxed and comfortable during and after acupressure because acupoint stimulation can release muscular tension, promote the circulation of the blood, and stimulate the body's natural self-curative abilities. They stated acupressure treatment to be safe, it has no side effects, and it is easy to perform[4]

The results of the controlled study showed a significant increase of the values of regional oxygen saturation on the stimulated side of the knee acupuncture stimulation was confirmed to increase the blood flow velocity of the peripheral arterioles. The values of regional oxygen saturation (rSO2) on the stimulated side of the knee were significantly increased immediately after acupressure stimulation[5]

Acupuncture excites receptors or nerve fibres in the stimulated tissue which are also physiologically activated by strong muscle contractions and the effects on certain organ functions are similar to those obtained by protracted exercise. Both exercise and acupuncture produce rhythmic discharges in nerve fibres, and cause the release of endogenous opioids and oxytocin essential to the induction of functional changes in different organ systems. Acupuncture has been accepted for pain relief in most countries and is commonly used in general practice and pain clinics as a complement to conventional treatment. heart diseases have been treated with transcutaneous nerve stimulation or acupuncture. Richter et al compared the effects of acupuncture and placebo in 21 patients with acute and stable angina pectoris. Treatment was given thrice weekly for 4 weeks. The number of pain attacks decreased studies demonstrate an immediate short-lasting effect following acupuncture but there is evidence that a longer-lasting effect is possible. Acupuncture induces in many patients an increased sense of well-being, calmness and improved sleep.[6]

Since the circulatory system supplies oxygen and nutrients to tissues and cells and removes toxic waste from them. It has also been noted that acupressure can significantly influence the heart rate (HR) and blood pressure (BP) or enhance local blood flow, such as in the lower limbs of patients with peripheral arterial occlusive disease[7]

Acupuncture is increasingly used in managing chronic pain and other conditions, such as chronic knee pain, tension-type headache, low back pain, and so on Li Shouxian said "It's not difficult to understand acupuncture point, but to master the manipulation; it's hard for us to

master the manipulation more than to understand acupuncture point; if only you merely comprehend acupuncture point, you couldn't be a distinguished doctor[8]."

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toxic waste from them,It has also been noted that acupressure can significantly influence the heart rate (HR) and blood pressure (BP) or enhance local blood flow, such as in the lower limbs of patients with peripheral arterial occlusive disease[8]

The Effectiveness of Acupressure on Relieving Pain says that acupressure is a complementary treatment that uses fingers and applies pressure to stimulate acupoints of the human body This noninvasive therapy was originally developed from traditional Chinese medicine, which focuses on the balance of yin and yang and maintains the function of vital organs through circulation of blood and energy (chi) in the body [9]

From previous studies of 'NASA - understanding space travel affects blood vessels' explains that using models that simulate microgravity, it is now evident that the shift of fluid toward the head and the unloading of postural muscles together alter the mechanical forces exerted on arteries, the vessels responsible for regulating blood flow and arterial blood pressure[10]

There's no gravity to pull blood into the lower part of the body. Instead, blood goes to the chest and head, causing astronauts to have puffy faces and bulging blood vessels in their necks.And appearance isn't the only ugly side effect..For the brain and heart to get enough blood, two things must happen. Blood must be returned to the heart from the legs and the stomach region. And once the heart pumps out the blood, the blood vessels must help generate enough pressure to drive the blood up to the brain.[11]

Lack of gravity can disrupt astronauts' blood circulation, giving them puffy faces and 'bird legs as blood moves from the lower body and congests in the head and chest. Our hearts and other muscles rely on the daily challenge of moving against gravity to stay strong and healthy. Long periods of sedentary behaviour – including sedentary behavior in space – are associated with higher risk of cardiovascular disorders such as high blood pressure, arrhythmia and heart failure.[12]

Living for months in microgravity can alter many of the body's systems astronauts who have stayed in space for long periods have problems with mainly the circulation and eyesight.Without gravity to pull fluids like blood down the legs, fluids shift toward the upper body, says Jennifer Fogarty, the head of NASA's Space Life Sciences Innovation. The heart still pumps enough blood to the lower limbs so that they can function, but the legs don't get nearly the same amount of blood as they do on Earth.[13]

Our Solution:
While researching we came up to 2 major problems that astronauts face in space - lower limb blood circulation and calluses. There has been very little research in this area, hence we decided to work on these problems. The reason this condition occur in space is due to the "lack of gravity" when there is no gravity , fluids naturally travel upwards into our face and head, causing lack of blood circulation in lower body, and as for calluses when there's no gravity astronauts float in space and rarely use their feet to move around causing the bottom layer of their feet to shed skin calluses.
To solve both the problems we came up with a easy solution- a sole which consists of
Acupressure points - while researching for a non invasive treatment for blood circulation we came across acupressure we decided to go with acupressure as our main treatment as acupressure is a simple safe natural efficient and a tested therapy to address blockages throughout the body, its mainly used for blood circulation.

Friction- as the feet of astronauts are not being used often giving fric.tion will help solve the problem of calluses even while they dont walk.
Now that we had a raw idea we started designing the sole the main challenge was keeping in mind the 3D printability but still get the desired outcome it took us 2 prototypes to come to the final idea
1st prototype- the first prototype is an outline sole, it is covered with contoured circles(acupressure points).

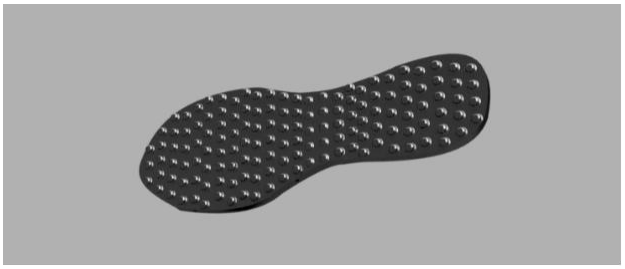

Fig. 6. 1st Prototype.

After studying the feet terminology we realised the contoured circles aren't required on the whole sole the mains parts of the feet that should be covered are the metatarsal, dorsal and plaunum. It was also very rigid for normal movements 2nd prototype- in the second prototype we designed a sole to accommodate the hinges 5 hinge placed 1 inch apart from each other the hinges helped in the flexibility of the sole. consisting of contoured circles (acupressure points). This will help astronauts move even on irregular surfaces.

Fig. 7. 2rd prototype with hinges at every inche .

After the 3D printing of the 2nd prototype, we realized the sole was very uncomfortable for wearing it for long durations. The main disadvantage we found was that only a specific point for acupressure was getting stimulated every time they wore the sole we needed to cover the entire feet but while giving it some friction, thus came up the idea of rollers that led us to create our third prototype
The designing of the roller:

Fig. 7. Roller with acupressure points.

Roller- we designed the roller keeping a 120-degree difference in every bubble to get the utmost pressure using minimal bubbles and at least one bubble is in contact with the feet while it is in a rolling motion. The length of the roller varied from 5.2 to 5.8cm depending on the curves of the sole. Bubble height was 0.55 cm the height was decided on the height of the outer sole so as to maintain the contact the bubble with the feet.

3rd prototype- in our third prototype, we made a semi-dynamic sole which consists of contoured circles on top of widely placed rollers. We used a toe grip to keep the feet from slipping. The outer sole was the place where the feet rests so that only a bubble only touches the feet and pressure until and unless it is pushed while moving.

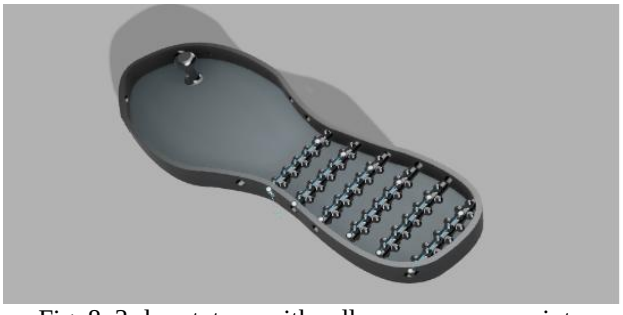

Fig .8. 3rd prototype with roller acupressure points.

After trying the third prototype, we realized that the rollers had two weak points, the skin tended to get stuck in the widely spaced rollers, second, the rollers also did not move because it had a space restriction to solve the problem we required a mechanism which made the rollers move each time the feet pressed on the sole so began the improvisations for the next idea Final prototype - This design consists of a rigid foot sole pivoted in the middle with a pin, toe grip, rollers with protruding bubbles, below the foot sole are attached a pair of leaf springs with rack and pinions are attached with the rollers.

Fig .9. final prototype.

To overcome the limitations of the third prototype we had to change the design of the rollers to incorporate a roller moving mechanism.

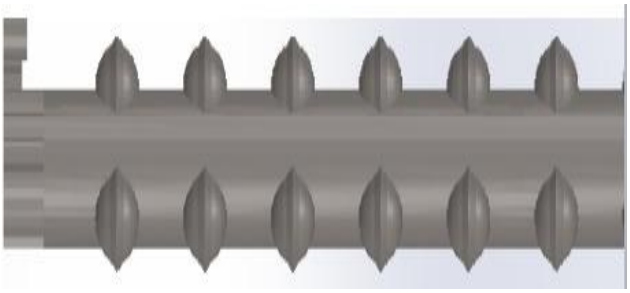

Fig .10. Modified roller with gear .

for moving the rollers we selected gears as the mode of transmission as it has the least power transmission loss. The selection of gear profile was based on the 3D printability, hence we chose the spur gear because it was the easiest gear profile to be manufactured by the 3D printer. After choosing the gear we were looking for a mechanism to move all the gears and thereby rollers at once. Simplest we could think off was gear train to move all the gears at the same time, but gear train would require a large amount of force to move every roller and cause a lot of wear and tear of the gear tooth. Hence the selection of rack and pinion mechanism

Fig .11. Rack and pinion mechanism.

we required such a mechanism that could give equal force to all the gear attached rollers. There are 10 rollers which need to move simultaneously but a gear train couldn't do so, so we went with a rack and pinion, (rack and pinion gears are used to convert rotation into linear motion).

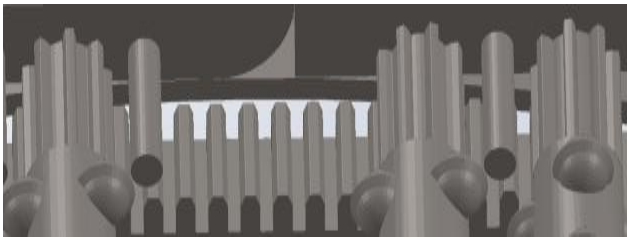

Fig .12. Rack and pinion mechanism used in final prototype

but to move the rack and pinion we required a mechanism to push and pull the rack to move the pinions in both directions i.e we needed a returning mechanism. The spring mechanism was selected to provide returning motion. To achieve that we needed repeatable counterforce when compressed or displaced would move all the rollers while maintaining contact with rack. This movement will not be achieved with the helical compression spring hence flat spring (leaf spring) type was selected to activate the movement, the use of leaf spring is also beneficial since it can support the extra weight. If we used a normal spring we would have to use a lot of them and it would cause a clutter so we chose a leaf spring, leaf spring advantages was that it had a pivot point and it could carry a lot of force.

Fig.13. Leaf spring.

The outer sole was changed to symmetric design because we wanted it to have a pivot point, a normal sole would have less width in the middle portion, that would weaken the mechanism and cause non-uniform motion of the rollers.

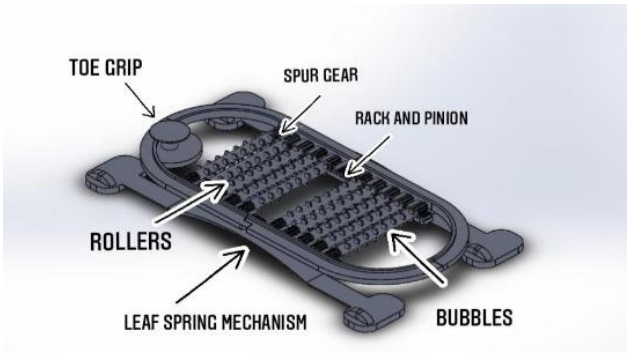

Fig.14. Final prototype illustrating all the parts.

The entire mechanism works when it is worn, the slightest bit of pressure puts the leaf spring under tension which then activates the rack and pinions that move linearly towards the heel side of the foot thereby moving all the rollers hence activating the acupressure points, once this foot pressure is released the spring under tension regains its original state while doing so the attached racks moves back to toe side of the foot thereby moving the rollers again hence reactivating the acupressure points. The testing of the final prototype in the microgravity remains to be done. This sole can be worn during their routine 2 hours workout regimen and also while they move around the shuttle.

Fig.15. Astronauts can use the sole during their workout routine.

Bubble for foot trouble solves
Calluses- through friction
Lower limb blood circulation- through acupressure
Acupressure also simultaneously helps solve
Lack of sleep
Minimizing head aches
Alleviating chronic pains
Relieving stress, tension and anxiety.
digestive issues.

III. CONCLUSION

This design is a unique way that light pressure on the foot activates the acupressure points and helps with the blood flow. Doing workout with this sole ON can improve lower limb blood circulation and help stimulate the lazy cardiovascular system due to longer stay in space. Acupressure research shows that regular stimulation pressure points increases oxygen saturation and microcirculation. Hence this sole can help overcome problems of lower limb blood circulation thereby solving problems like feet skin shedding, skinny legs, puffy face and could reduce intracranial pressure.

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