Microgravity, Levitation and Plastic Surgery

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"27th September, 2007, Dr Dominique Martin, Professor of plastic surgery at the Bordeaux University in France, performed the first operation on a human in weightlessness. He removed a 3 cm lipoma from the forearm of a 47-year-old man on board of an Airbus A300 in "spatial" conditions. For 3 hours, the A300 (of the European Space Agency) climbed and descended at altitude, during which the passengers found themselves weightless 32 times for about 20 seconds each time. In total, the operation lasted less than 10 minutes. To perform this operation, 3 surgeons and 2 anesthetists were attached by restraint harnesses, with straps and carabiners attached to rails fixed to the floor of the Airbus. Military paratroopers supervised them. In order not to float in the air, the working instruments, smaller than in an ordinary operating room, had to be rested on powerful magnets. The patient, under local anesthesia, was simply tied up. The objective of this operation was to test the first operating room in the world with space standards," which could be used as a prototype to operate in the space." (1)

Before this world premiere on a human being, Dominique Martin, renowned expert in microvascular surgery, proceeded in various experiments. For example, in September 2003, in the same conditions described above, he succeeded to perform the suture of a 0.5 mm artery on a rat's tail by using 7 stitches of 10 × Omonofilament sutures.[1]

Since Dominique Martin's first achievements, space travel and plans for long-term stays on the planet Mars have multiplied, and with them a host of questions about the effects of weightlessness on astronauts and the possibility of remedying the injuries and illnesses they might suffer. For situations requiring surgical treatment, research has focused on determining what problems might arise in microgravity and what methods could be applied. in addition to microgravity, several other conditions can affect health and recovery after an operation in space, like the lack of oxygen or variable atmospheric pressure. However, unlike microgravity, these conditions can be supplemented through suitable devices.

GRAVITY AND THE STUDY OF THE EFFECTS OF MICROGRAVITY

In spite of extensive research from the most outstanding scientists, a clear definition of gravity is yet to be found. Among the 4 fundamental forces which "rule" the universe, gravity is probably the most intuitive and familiar, but it is also been 1 of the most challenging to explain. According to Newton law, every mass in the universe attracts every other mass. The attractive force between any 2 objects is directly proportional to the product of the 2 masses being considered and inversely proportional to the square of the distance separating them. The greater is the mass of the attracting objects, the greater will be the force of attraction, the farther apart the objects are from each other, the smaller the attraction. For astronauts, attraction on the surface of the Earth (g) is measured as 9.807 m/s^2, compared to 1.62 m/s^2 on the Moon, and 3.721 m/s^2 on Mars. In practice, a human body weighing 70 kg on Earth, will weight 27 kg on planet Mars, 11 kg on the Moon and near zero in space.

When exposing humans, animals or tissues to microgravity for experimental purposes, there are several possibilities, differing in the duration of the experiment and other parameters. To achieve weightlessness, the absence of the sensation of weight, the most common way is through free fall. A misconception about free fall is that the force of gravity disappears. In reality, during free fall, only the force of gravity is present, but it is not felt unless there is some opposing contact force to counteract it, for example the upwards force exerted by the ground when standing up. Free fall can be achieved in so-called drop towers, where the duration of the microgravity time is relatively short (3.5–4.7 seconds). Parabolic flights, like the 1 used by Dominique Martin, are another type of free fall and are conducted in a customized aircraft providing short periods of microgravity. To produce a free fall period the plane is flying parabolic trajectories consisting of 3 phases: First, the aircraft climbs at a steeper angle until 45° is reached, producing hypergravity. Second, the airplane follows a ballistic trajectory, also known as a parabola. In this second phase, the aircraft is in free fall and the subjects will experience microgravity in the range of 20 to 25 seconds. At the apex of the parabola, the aircraft nosedives until a decline angle of 45° is reached, thereby entering the third and last phase of the parabola, in which the airplane again experiences hypergravity (Fig. 1). The best mean to study microgravity can be obtained onboard a spacecraft, for example during a resupply mission to the International Space Station (ISS). However, only a few studies have been reported using this rare option.

Devices to study altered gravity conditions on Earth, in an attempt to reproduce the conditions achievable in orbit, have been used mainly for biological experimentation. The Clinostats use rotation to negate the effect of gravitation. Subjecting the cells to rotations, either constantly or through directional alterations, will suppress cell sedimentation. Clinostats have been used mainly to study plant growth, stem cells and tissue cultures.

PHYSIOLOGICAL MODIFICATIONS IN MICROGRAVITY

Gravity has influenced the development and the genetic of animal life since the first protozoa. The size of a single cell is inversely

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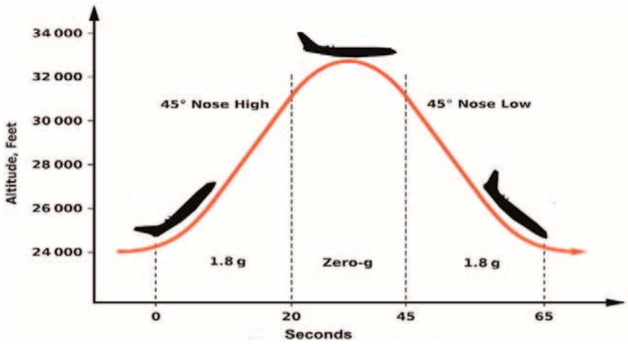

FIGURE 1. The phases of the parabolic flight.

proportional to the strength of the gravitational field exerted on the cell. That is, in stronger gravitational fields the size of cells decreases, and in weaker gravitational fields the size of cells increases. Gravity is thus a limiting factor in the growth of individual cells. Microgravity may induce profound multi-systemic consequences to human physiology. On Earth, gravity pulls fluids to the lower extremities, as in space, fluids tend to redistribute evenly throughout the body, increasing the volume of blood returning to the heart. On Earth, this stroke volume increase is usually accompanied by acceleration of heart rate, but in weightlessness, distension of the upper-body vasculature induces carotid baroreflexes, which cause a reduction of heart rate via a parasympathetic effect. Despite no alteration to total body fluid volume, the distension of large central vessels produces another paradoxical change affecting the renin-angiotensin-aldosterone axis, resulting in hemoconcentration. Long-term exposure to these conditions may result in chronic decreases of heart rate. Upon return to Earth, this prolonged cardiac deconditioning may cause severe orthostatic intolerance, necessitating a significant readjustment period.[2]

SURGERY AND ANESTHESIA IN WEIGHTLESSNESS

Procedures that have been evaluated on animals include surgical site preparation, positions and restrains of the potential surgeons, use of magnetizing surgical tools to sticktotheoperatingtable,methodsof anesthesia, opening and closing of wounds, laparotomies, peritoneal drainage, thoracotomy, thoracoscopy, minimally invasive surgical procedure such as laparoscopy, repair of vascular injuries, control of hemorrhages. A few uncommon situations that differ greatly from practice of surgery on Earth have been encountered. For example, the intestines are essentially free floating within the abdomen, tethered only to the posterior abdominal wall by the mesentery. Consequently, the small bowel may freely float out of an abdominal incision, creating a risk of contamination or damage. Incases of bleeding, blood does not collect or pool in the same way it does on Earth, but instead forms domes or miniature droplets on surfaces. If these domes are disrupted by instruments, blood may float off the surface, potentially creating a biohazard. However, if the blood is not being pumped physically out, it tends to remain under surface tension. Minimal research has been done in the applications of anesthesia to crewmembers during spaceflight. Inhalation of anesthetics that are used on Earth remains a challenge for crew members in spaceflight as an anesthetic gas leak could contaminate the closed loop environment on the ISS. Spinal anesthesia also poses a problem as the anesthetic may be distributed differently due to the cephalad fluid shift that occurs in microgravity, thus limiting the uses of such anesthetic delivery. Local and regional block and intravenous sedation may remain the safest method to deliver an aesthesia.[3,4]

WOUND HEALING IN MICROGRAVITY

Cosmetic or complex craniofacial procedures will certainly never be performed in space or on a microgravity planet. However, post-traumatic wounds, facial fractures or burns affecting astronauts cannot be excluded and might necessitate plastic surgery operations.[5] In this context the study of the effect of microgravity on the various aspects and phases of wound healing could potentially be helpful and has indeed become the subject of several studies. Since 2014, an international experiment headed by the Italian scientist Monica Monici, entitled Wound Healing and Sutures in Unloading Conditions, has been selected by the European Space Agency, with the objective to investigate the behavior of in vitro sutured wound models in real microgravity on the ISS.[5] A recent review collecting more than 150 papers on this subject concludes that microgravity may influence the process of wound healing and its progression either by changing the tissue response, the rate of apoptosis or the suture behavior.[6] Stimulated microgravity induces changes in cytoskeleton; thereby it regulates the behavior of endothelial cells in terms of cell proliferation, adhesion, migration, production of extracellular matrix, and translocation of bioactive molecules inside the cells.[7] There was, however, no major deleterious outcome on the wounds which had been treated conventionally, confirming the first human operation in zero-gravity performed by Dominique Martin. A particularly interesting study suggests that, in a clinostat, microgravity promotes human umbilical vein endothelial cell's migration and could enhance angiogenesis.[8] Most plastic surgery procedures could, therefore, be performed in space or on a low gravity planet without adverse effects. The main problems to be solved are the positions and restrains of the patient and the surgeon, as well as the handling of instruments and tissues. A free-floating skin graft might be difficult to secure on a wound!

LEVITATION AND THE USE OF ANTIGRAVITATIONAL FORCES

Levitation is the process by which an object is held aloft, without mechanical support, in a stable position. Levitation is accomplished by providing an upward force that counteracts the pull of gravity (in relation to gravity on Earth), plus a smaller stabilizing force that pushes the object toward a home position whenever it is a small distance away from that home position. For plastic surgeons, prevention and correction of deleterious effects of long-term gravity on the human face and body is undoubtedly a field much more common than plastic surgery in space. Numerous operations have been designed to lift and support the female drooping breasts and the sagging of skin and soft tissues in the aging face[9]. Decreasing the force of gravity is not an option in these situations. There is, however, an important field where minimizing the earth attraction on the body may provide great services, that is the relief of excessive pressure on lying patients with severe burns, decubitus ulcers or postop skin flaps. Various types of beds have been designed for this purpose. Since the late 60 s, engineers got the idea of constructing levitation beds on air cushions, on the model of the air-cushion vehicle (Hovercraft) capable of travelling over land, water, mud, ice, and other surfaces. This Air-fluidized therapy bed supports could maximize the envelopment of the body, whereas significantly reducing shear, friction, pressure, and mechanical stress applied to the skin and subcutaneous tissue. This type of ''levitation beds'' have a pressurized chamber, the outlet of which is formed by a plurality of inflatable pockets arranged as a mattress for underlying a patient. In the High Air Loss Bed System-Levitation, the patient is placed on the bed when it is inflated with air at maximum pressure. The air pressure is then slowly reduced until the torso depresses along the midline of the bed and allows air to escape between the body and the upper surface of the pockets. For later stages of treatment of burn injuries, a Low Air Loss Bed System had also been devised, by interposing a suitable vapor permeable film between the skin and the air.[10,11]

These first types air fluidized levitation beds have been replaced since the 70 s by the so-called Clinitron, where the patient is bedded in a mass of silicon-coated microsphere, which are swirled by the application of a strong air current to support the body in a floating condition. An air permeable filter sheet separates the microspheres from the patient. When warm air is driven up from beneath with pressure sufficient to overcome their weight, the beads are lifted into the air stream and lubricated from another. The micro glass balls facilitate the absorption of liquids such as exudates and excessive liquids can be transported away from the patient.[12] Extensive use of this technology over the years has led to its wide acceptance as a top-of-the-line support surface.[13] Although air-fluidized support surface therapy is now widely used in most plastic surgery wards, it has also several drawbacks such as dehydration, and problematic patient care and handling. A few patients complain of discomfort, and the instability of the surface interferes with their movements in side lying and semi-Fowler's positions.[14] The perfect levitation bed has yet to be invented.

THE FLYING FROGS

Levitation (on Earth or any planetoid) requires an upward force that cancels out the weight of the object, so that the object does not fall or rise. Magnetic levitation is the most commonly seen and used form of levitation by the physicists. This type of levitation has been developed for transportation systems. For example, the Maglev (magnetic levitation) is a train that is levitated by a large number of magnets. Due to the lack of friction on the guide rails, they are faster, quieter, and smoother than wheeled mass transit systems.

In 1997, the physicist Andrey Geim initiated a research on direct diamagnetic levitation of water, which led him and his colleague Michael Berry to make frogs levitate (Fig. 2). As Geim explained later: "Contrary to our intuition, apparently nonmagnetic substances can be levitated in a magnetic field and can stabilize free levitation of a permanent magnet. Most substances are weakly diamagnetic and the tiny forces associated with this property make the 2 types of levitation possible. Living things mostly consist of diamagnetic molecules such as water and proteins and components such as bones and, therefore, can be levitated and can experience low gravity. In this way, frogs have been able to fly in the throat of a high field magnet."[15] Berry added: "The magnetic field that holds up the frog is a few times stronger than the fields used medically, in magnetic resonance imaging. In principle, a person could be magnetically levitated too, like frogs, we are mostly water. The field would not have to be stronger, but would have to fill the much larger volume of a person, and that has not been achieved yet. I have no reason to believe such levitation would be a harmful or painful experience, but of course nobody can be sure of this. Nevertheless, I would enthusiastically volunteer to be the first levitate." For this extraordinary experiment, Geim and Berry received in 2000 the Ig Nobel Prize (the Ig Nobel Prize is a satiric prize awarded annually since 1991 to celebrate ten unusual or trivial achievements in scientific research) in physics. In 2010, Andrey Geim was awarded the official Nobel Prize of physics for his discoveries on graphene.

The flying frogs experiment showed that animals can be maintained in levitation by magnetic forces. At a time when so many progresses are being made in physics of astronautics, gravity and microgravity, it is tempting to speculate that, 1 day, a few patients could benefit and recover in a magnetic levitation bed.

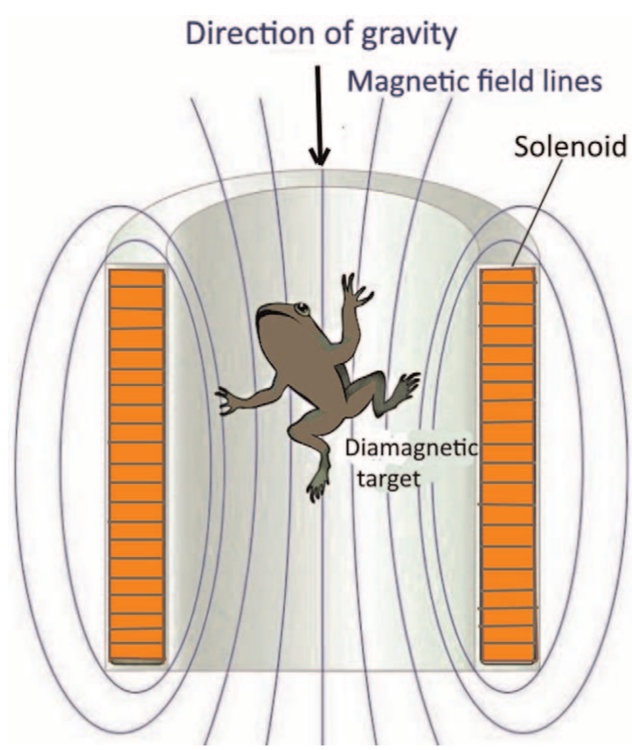

FIGURE 2. The flying frog experiment of Geim and Berry.

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