Physical Disability in the Microgravity Environment: Factors for Consideration in the Human Spinal Cord Injury Model.

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Abstract

This paper outlines preliminary areas of discussion in the relationship between human venture into space and the microgravity environment and physical disability, in particular high thoracic complete neurological dysfunction due to spinal cord injury (SCI). (As example)

The purpose of this paper is to present a disregarded yet vital research opportunity and to provide a starting point for academics that may be wish to explore this area further. A brief overview of the effects of spinal cord injury and perceived complications and research benefits in human SCI[1] spaceflight are given. Spinal cord injury has been chosen as the research model because: 1/. Many of the effects suffered by persons with a chronic SCI condition are comparable to those suffered by able-bodied persons during spaceflight; 2/. The areas of healthcare already under study in microgravity can be well complimented by studying the reaction of the SCI condition in microgravity; 3/. Persons with SCI are (generally speaking) otherwise completely fit and healthy; even so far as SCI is no longer regarded at an unhealthy (or sick) condition; 4/. The effects of SCI are static and well documented.

As well as being drawn from both personal and personally acquainted life experiences, the text also has references drawn from other published articles that support the hypothesis that persons with SCI may well be better suited to long term habitation of the microgravity environment. This paper reveals the human chronic SCI model in microgravity as a good research sample for investigations into these research topics: 1/. Osteoporosis. 2/. Muscle degenerative disorders. 3/. Cardiovascular function. 4/. Pulmonary function. 5/. Autonomic function 6/. Metabolic and renal function 7/. Neural plasticity. 8/. Sleep disorder 9/. Activities of daily living. Two further topics introduced are the social and cultural understanding of disability and solo parachute freefall with paraplegia.

Upon that it describes physiological effects and side effects of high thoracic (and lower) neurological dysfunction due to spinal cord injury as not lying in contrast with spaceflight opportunities: Indeed, many of the effects of long term habitation in a microgravity environment by the so far able bodied pioneers are experienced continuously by those living with physical disability in a +1g environment. Though some of these might make spaceflight more enduring, others may make microgravity habitation, and indeed recovery from it easier than it is for the able bodied and certainly easier than disabled habitation of a +1g environment. Few activities of daily living become impossible. Even in the most extreme examples of bowel and bladder dysfunction; human ability has provided solutions. Early pioneers of Space were presented with awkward pre-requisites for adaptation of personal care, and sometime quite similar to personal care within SCI bowel/bladder dysfunction. Spaceflight may be inhibited if routines cannot be adjusted to accommodate the new conditions, but overbearing adaptation of already well practiced personal routines may not be necessary.

Importantly, there is a massive cultural understanding to be gained from the knowledge that it is our own earthbound annealed environment that dictates the refinements of physical disability.

It is the conclusion of this paper that the benefits of exploring microgravity habitation with a physical disability such as spinal cord injury outweigh the pitfalls, and that not only spaceflight and medical research but also the “human experience” would greatly benefit from exploring this option. There are no apparent prohibitive contraindications to human SCI spaceflight.

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[1] Denotes Spinal Cord Injury

1. Introduction

This paper is intended to provide a starting point for academics, researchers and specialists that may wish to follow this important yet until now disregarded area of research further. It's intended to illustrate areas or particular importance and of interest to other research fields including that of spinal cord injury (SCI). To this end this paper draws on published material by other authors: material that is already known but may not until now have been associated with spaceflight opportunities.

In many instances the evidence I give will be anecdotal, but it is felt of particular relevance because it is from a patient's point of view.

It is believed by the author that the human spinal cord injury model is of particular usefulness to research in the field of physical disability in space because of it's wide range of symptoms and its static prognosis.

2. Reading Guide

Two essential publications for reading (English language, UK publications) in SCI clinical care and rehabilitation are : "ABC of Spinal Cord Injury" By David Grundy and Andrew Swain (Published by BMJ: ISBN 0-7279-0760-3) and The Spinal Injuries Association "Moving Forward" (Published by SIA ISBN No: 0-953-1237-4)

All the resources, with the exception of the illustrations, were sourced from the United States National Library of Medicine "National Center for Biotechnology Information" internet site at **http://www.ncbi.nlm.nih.gov** using their PubMed search engine. It is strongly recommended that this site is visited and the referenced abstracts are downloaded using the PubMed ID number given in Table 1. Hyperlinks to the abstracts are embedded within the reference annotation numbers.

These abstracts will provide a further insight and will provide an immediate reference for academics, researchers and leaders in business; fresh to and interested in the concept of human spaceflight with spinal cord injury (SCI). Please take advantage of them.

It should be recognised, though, that to some extent all spinal injuries are different; patient perspectives and motivations differ; and nothing can be better than a personal understanding. This should be taken into account throughout this paper.

3. A Brief Overview of Human Spinal Cord Injury

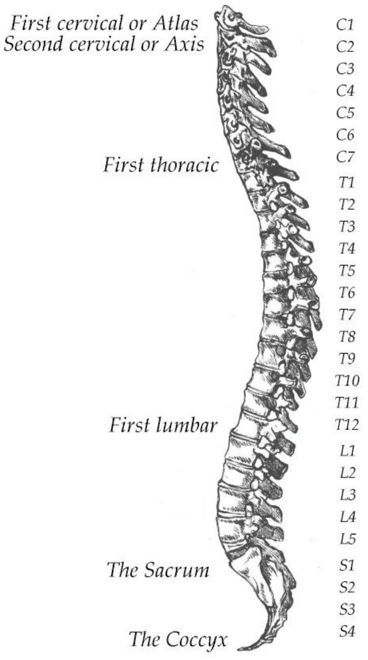

Figure 1. The human vertebral column

The vast majority of spinal cord injuries are bought about by trauma. Others may be bought about by infection or disease. Whichever the cause the result is always the same: After (as example) injury in a road traffic accident the patient will be taken gently yet quickly to the nearest trauma center, where the condition will be properly diagnosed and the prognosis given. This diagnosis may range from partial neurological transection of the cord in the lower back to complete transection in the neck. In the severest of injuries the patient may require a ventilator to breathe and will have no use of any limbs or control of any bodily function; accompanied by complete loss of sensation below the level of injury. In any spinal cord injury there is no way to cure the injury but huge advances have been made in rehabilitation therapy in the last decades: so much so that persons with SCI have the same life expectancy and in nearly all cases an acceptable quality of life. Fulfilling employment and business opportunities are available; many somewhat adventurous outdoor activities are taken up by some. Skiing and mountain climbing seem to be the most popular.

Once in the trauma center and the injury has been properly diagnosed a range of care options are available. Depending upon medical management; the broken (and / or dislocated) vertebrae may be fixated or the patient may be put in traction so that the broken and dislocated bone may fuse correctly. It is often the great skill of the radiographer and of the specialist consultant that achieves a great improvement in the prognosis. It is unusual for the spinal cord to be physically cut: The human spinal cord has an elasticity that exceeds the usual range in dislocation of the vertebrae with most injuries. Paralysis usually occurs as a result of the Spinal Cord being starved of oxygen due to swelling due to bruising. Damage can extend for some distance along the cord.

Immediately post injury the spinal cord will fall into a state of shock, much like cerebral concussion: In the following weeks swelling will also subside and some function and sensation may or may not return. This may be accompanied by increased pain, phantom or otherwise. If left untreated this pain may result in chronic uncontrollable discomfort. Together with stabilising the dislocated vertebrae correctly and advanced prescription therapy the physiotherapist can achieve astounding rehabilitation results with the patient. Generally speaking the lower down in the spine the injury, the more physiotherapy orientated the rehabilitation: The higher the injury, the more occupational orientated the rehabilitation is.

Paralysis and loss of sensation are only a small part of spinal cord injury. The effects of SCI are legion and a great knowledge in these is passed, with a wholistic approach, on from therapist to patient. The most important of these is "Autonomic Dysreflexia" (AD). Any neurological injury at level T6 or above can result in susceptibility to this condition, which is characterised predominantly by high blood pressure in response to physiological and psychological extremes such as stress or painful stimulii. AD can result in the patient suffering a stroke or heart attack and is life threatening. the patient is made critically aware of this and is taught how to avoid it and what to do as soon as, and if, it sets in.

Any injury that affects control of the Sacral nerves will result in change in function in the muscles of the bowel and bladder. In higher injuries many reflexes may be retained. The bladder or bowel may fill normally until pressure or bulk increases and stimulates an uncontrolled reflex to empty.

The patient is taught how to manage his or her own medication, how to look after their skin, how to lead an as active a life as possible and within that to pay particular attention to the dangers and mortality of pressure sores and general health. Diet and lifestyle are particularly important factors in maintaining good health. Upon discharge from the specialist rehabilitation unit the patient will have a good working knowledge of their condition, and will look after their own personal care needs as much as they either want to, or are physically able to. Most paraplegics are fully independent. Many lower level injury tetraplegics[2] are also fully independent and capable but the level of independent ability falls the higher the injury. Rehabilitation can range from a few months to over a year in the severest of conditions.

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[2] Tetraplegic is UK terminology for the USA Quadraplegic (Cervical / neck spinal cord injury).

4. Osteoporosis

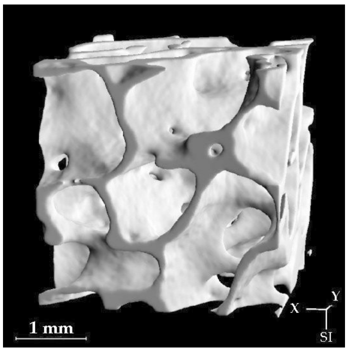

Figure 2. Normal bone

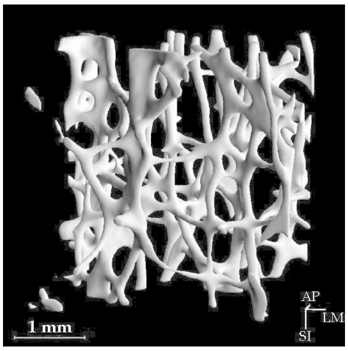

Figure 3. Osteoporotic bone

(Pictures courtesy of ERISTO: European Research in Space and Osteoporosis).

Extensive research has been conducted to evaluate osteoporosis in bed-rest, spinal cord injury [References 1, 2, 3, 4, 5][3] as well as in microgravity [References 6, 7, 8, 9]. In order to better understand how microgravity effects the human skeleton it may be better to study how the human chronic[4] spinal cord injured skeleton reacts under microgravity conditions. This could benefit research in age related and spaceflight skeletal degenerative conditions as well as support the hypothesis that the chronic immobile spinal cord injured skeleton is better suited to spaceflight than the able-bodied.

It seems that decreases in bone density due to chronic spinal cord injury vary widely from individual to individual. Decrease appears due in the larger part to the absence of load bearing rather than purely the paralysed condition. The main influences on this variation are recorded as being metabolic activity and type and length of physical activity[5]. Physical activity may include muscle spasticity. Decrease in bone density appears to approach stasis in most cases (though sometimes near fracture).

It could be hypothesised that if a human spinal cord injured (paralysed) subject with a near stabilised decrease in bone density in the lower extremities and lumbar region were to be exposed to microgravity, then there may be no further decrease or at least any microgravity influenced decrease in bone density may be less severe. Imbalances caused by bone degeneration may be avoided. A chronic (human) paraplegic may have better skeletal durability to spaceflight.

The recommendation is that a suitable spinal cord injured subject is found. A suitable subject would have a stabilised bone density, and bone density should not be near / at or approaching fracture: Once this has been established; and considering that rates of osteoporosis are seen to vary across cross-sections

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[3] These numbers are hyperlinked to the referenced abstracts in the electronic copy. Please connect on-line and click on the digit if you have it.

[4] The time post for change from the acute condition to the chronic condition appears to be largely subjective and varies from case to case. Chronic, in this paper at least, refers to the extended more settled condition.

[5] Excepting in the upper limbs and torso where there appears to be a genetic pre-disposition for resistance to osteoporosis.

of subjects, their bone density should be recorded at specific points above and below their level of injury and then exposed to microgravity in two stages. The shorter duration should give an early indication of any serious detrimental effects of microgravity to bone density. If all goes well a longer (90 day or more) study should then be undertaken. Immediately after each exposure to microgravity bone density should be measured again; and the results compared to able-bodied spaceflight samples. Within this data collected there should be a record (diary) of any muscle activity[6].

The data gained would provide for better interpolation of data recorded on the effect of microgravity on bone density in able bodied spaceflight, better supporting studies in immobilisation osteoporosis; by separating the effects of microgravity from acute immobilisation.

5. Muscle Degeneration

Muscle degeneration, whether due to spinal cord injury or spaceflight can be severe. It is well recognised that muscle loss is variable and rapid [References 10, 11, 12]. Some influence on the rate and extent of muscle atrophy is unusual muscle activity (commonly referred to as spasticity) due to neurological dysfunction. Changes differ between type and function of muscle fibers [Reference 13]. Further influence on spasticity might be changes in calcium handling [Reference 14]. Complications can arise as a result of decreases in muscle bulk and some of this is described later[7]. Innovative general and local treatment for severe muscle spasticity can be found in [References 15, 16].

Muscle atrophy whether due to spinal cord injury paralysis or from microgravity disuse [References 17, 18, 19, 20, 21] falls within similar boundaries. Chronic paralysis results in a far greater deterioration in the quality and bulk of human muscle fibers than due to bed rest only. (Indicating that neurological "completeness" itself contributes to good muscle tone.) This loss is still to some extent recoverable; though most recovery so far gained has been with Functional Electrical Stimulation. Recovery from long term able-bodied spaceflight may result in a near normalised condition but in the absence of exercise, and by that is meant intense exercise, muscle atrophy will be severe and recovery can be slow.

If a spinal cord injured person were to inhabit a microgravity environment that person may not have to undergo the same intense exercise routines to maintain their already markedly reduced muscle tone / bulk. The SCI person would not only have more time for maintenance or research duties, but may also have a shorter (or need no) recovery period[8] post-flight. However, it is important to recognise that a paraplegic exercise their upper limbs: Even though the course of the normal working day may provide enough exercise to prevent extensive upper limb muscle atrophy under able-bodied conditions; on return to Earth the paraplegic will use their upper limbs in different ways, and so will need to maintain a different type of upper limb function. It is important to note that in the course of a paraplegic's normal day it isn't so much brute

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[6] See "Muscle Degeneration".

[7] Cardiovascular function.

[8] Recovery to pre-flight condition.

force that is needed, but flexibility / suppleness and stamina. For me, the most useful physiotherapist routines for the paraplegic model was pushing down on a pullied load with laterally extended arms[9]; and in a floor-seated position, with legs out-stretched forwards, raising the backside off the ground as high as possible by using the arms with full downward shoulder extension. These exercises aid transfers and that ability should not be lost. Spaceflight exercise routines should accommodate these.

My main concern with muscle activity in spinal cord injured spaceflight would be that of spasticity. Spasticity in spinal cord injury is particularly prevalent in incomplete higher level injuries. In extreme cases an incomplete paraplegic or tetraplegic patient that may otherwise have useful function of the limbs can be almost completely debilitated by their spasticity if it is left untreated[10]. There may be problems with contracture and increased shaking of the limbs leading to impaired passive mobility and decreases in comfort and cosmesis.

Spastic contracture may occur in paralysed limbs if the brace effect of a snuggly fitting wheelchair is left behind, especially if the subject has used a wheelchair for many years. It could also be very useful to have a light-weight leg-torso brace fitted to inhibit over extension of the legs and back. This could also aid mobility in microgravity by making for a more stable posture. Anecdotal evidence from myself and from other spinal cord injured persons I have come to know suggests that leading an active and mobile lifestyle on it's own often results in improved (lessened) spasticity. Exercise of the paralysed limbs should be taken in microgravity, but the assumption can be made that exercise needn't be anything like as intense or load-bearing as in able-bodied spaceflight. Many SCI patients have improved lower limb muscle bulk and blood flow due to some spasticity in the legs and improved stability from mild spasticity in the torso: Often a careful balance between useful and detrimental spasticity is maintained, and in nearly all cases medication or other (exercise) therapy is governed by the patient[11].

6. Cardiovascular Function

The effects of spinal cord injury on cardiovascular function [References 22, 23, 24, 25, 26] and the effect of microgravity on cardiovascular function [References 27, 28, 29, 30] are shown to differ. A better knowledge of the mechanisms behind these differences and a better knowledge of the common links between them could benefit human long term microgravity habitation and Earth based medical research. This section gives an overview of some of

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[9] This exercise strengthens the Latissimus Dorsi muscles, a sprung load should be used in place of "weights" in microgravity.

[10] Pharmaceuticals used to control spasticity in SCI include Baclofen , Dantrolene, Valium and more modernly intramuscular Botulinum toxin. In extreme cases the peripheral nerves may be surgicaly severed to break the neurological loop that enables uncontrolled reflexes to take hold. Research into the use of Cannabinoids to control spasticity is currently ongoing with some success.

[11] Anecdotal evidence suggests that a wholistic approach is taken, and that even passive mobility relieves severe spasticity.

the common ground and areas of interest in studying spinal cord injury cardiovascular function in microgravity.

A major influence on blood flow in spinal cord injury is muscle disuse rather than change in cardiac output: A common result of the absence of the pumping action by the leg muscles is odema in the lower leg and foot. Spaceflight seems to result in a more headward shift of (and decrease in) fluid volume. This is described as being similar to that of a siting position. It would be interesting to know what change in volume and flow occurs in the paraplegic model when exposed to microgravity. Would venous return be improved? Would fluid volume decrease further? Pressures and cardiac output would appear to remain the same or closely similar. So if a cause (gravity) of poor venous return in SCI were to be removed, flow may be more equalised. Blood flow in the lower limbs may even be improved, leading to a reduced likelihood of thrombosis in the paralysed legs and improved overall condition of the legs and skin.

If cardiac output remains the same (or closely similar) in spinal cord injury as well as in microgravity, and changes in blood flow differ under differing causations, then it could be better understood how gravity and how muscle disuse separately influence fluid volume (and shift) in microgravity (If it were to be studied in a paraplegic in microgravity): Because recorded changes would be measured in an already chronically immobile (disuse) system; the effect of disuse in interpretation of collected data could be on the one hand nullified, and with regard to previously collected data on the other; better understood.

7. Pulmonary Function

Pulmonary function is obviously an important aspect of wellness. Both are disrupted, and in different ways, by spinal cord injury [References 31, 32, 33] and by microgravity [References 34, 35, 36]. Correlations and differences can be drawn between these two differing mechanisms by paying regard to the given abstracts.

Changes in lung capacity and tidal volume in SCI appear to be due to posture as well as paralysis. Paralysed subjects normally have a degree of difficulty in achieving full breath and exercise has little or no effect on lung capacity.

A greater level of uniformity in lung capacity appears to arise in microgravity. It could be assumed that the removal (due to microgravity) of some internal weight bearing pressures and a more beneficial posture (i.e. not seated) might improve lung capacity. Quite what this effect might mean to the paralysed subject in microgravity (and indeed closely linked vascular function) is unclear. Pulmonary function *may* be improved, but what benefit this may mean to oxygenation can only be discovered by undergoing spaceflight.

Hypothetically though, if microgravity does remove some of these internal weight bearing pressures; and thus make breathing 'easier' for a SCI subject: Then with regards to pulmonary function, and considering the chronic state of SCI immobilised physiology the effect of microgravity may be less detrimental than in a "fit / healthy" non-paralysed physiology. Only an in-flight study would clarify this.

8. Autonomic Dysreflexia (AD)

The autonomic system possesses characteristics that control some aspects of cardiac and pulmonary function as well as controls in body temperature and immunity against infection (amongst others). Without going into these here it should be recognised that the autonomic system has dysfunction in high thoracic and above spinal cord injury and should be monitored incase of dangerous complications. This section is briefly added merely to recognise this and introduce factors that may have to be held in regard to considerations introduced in previous topics. It should be stressed here that any person examining autonomic function in human SCI spaceflight should have an understanding of Autonomic Dysreflexia (AD): An introduction to this can be found within the suggested reading "ABC of Spinal Cord Injury".

Considering that injuries to the spinal cord at level T6 or above can lead to life threatening autonomic dysfunction special consideration should be paid to monitoring autonomic activity in high thoracic (or cervical) spinal cord injury [Reference 37]. There doesn't appear to be any evidence to suggest that Autonomic Dysreflexia might occur directly as a result of exposure to microgravity; but responses to stress (especially) should be monitored. Any SCI patient that is susceptible to AD should already be aware of how to avoid it and how to combat it. AD is an emergency condition and steps must be taken to provide for (self care) emergency treatment (or preparation) to counter-act it.

There may be influences other than microgravity (or stress, acute injury or chronic discomfort) that could bring about disruption to autonomic function and dysreflexic responses in SCI. Reductions in blood / fluid volume and alterations in capillary physiology may be one. Another interesting example is given as being the possible perturbative influence on autonomic function of magnetic storms: What effect magnetic storms [Reference 38] might have within a severed autonomic loop is unknown. There doesn't appear, though, to be any evidence to suggest that spaceflight could directly give rise to AD and an inability to counteract it.

However, one consideration that must be paid to is the possibility of a need to counteract AD during procedures where the wearing of a spacesuit is required. This would obviously prohibit any hand to mouth action that would be essential to the self-administration of remedial Nifedipine (or other) medication.

This area certainly requires further examination previous to SCI spaceflight: It is suggested that simulations of stressful stimuli in simulated strong electromagnetic environments are undertaken and physiological results examined to ensure that "Magnetic Storm Induced Autonomic Dysreflexia" is not a risk. Monitoring of the autonomic system and blood pressures would most likely be undertaken as part of the general study of human spaceflight with spinal cord injury.

It should be noted, though, that deliberate induced onset of AD is a contraindication to research. So, for the purposes of investigation a study should be taken on the effect of extremes in electro-magnetic fields on human SCI neurology / physiology and safeguards taken to protect against AD, like ending the experiment and immediate sublingual administration of 5mg of Nifedipine.

9. Metabolic, renal and hormonal function

Some metabolic dysfunction due to microgravity and it's physiological consequences may be attenuated in spinal cord injured spaceflight when compared to able-bodied spaceflight: It could be assumed that the resultant deleterious effect on the metabolism and on renal function in particular may not be so severe. If these imbalances are less severe then the Human Spinal Cord Injured Model may again be more appropriate for long term spaceflight. Further reading on metabolic, renal and hormonal function in spinal cord injury [References 39, 40, 41, 42, 43, 44, 45, 46, 47, 48] and in spaceflight [References 49, 50] is suggested and their relevance to aspects of other sections regarded.

In overview (and in particular) there may be less likelihood of renal stones and temporal dysfunction bought about by calcium imbalances from bone density loss. There may be less pathogens in general released into the system and thus less strain on general physiology. There may be further factors such as thyroid and hormonal *that may or may not* undergo degradations in efficacy. Again, in the chronic human SCI model these are already shown to have undergone some reduction (and are generally left untreated). These factors should again be monitored in similar fashions to previously undergone examinations (described in referenced papers) and any changes compared to previously collected data on able-bodied spaceflight.

Many of the changes described are brought about as a result of immobilisation rather than the influence of microgravity. Again, a chronically immobile subject may suffer less alteration in metabolic physiology upon acute exposure to microgravity.

However, many spinal cord injured persons will have their good health and quality of life supported by the administration of carefully selected pharmaceuticals and consideration should be paid to this. Doses may have to be altered or alternative prescriptives sought. These effects are due largely to alterations in circulatory function and osmotic actions.

10. Neural Plasticity

The human central nervous system (CNS) of which the spinal cord is a part, does not show significant repair or regeneration in vivo [References 51, 52]. Schools of thought do exist that the human spinal cord attempts repair but is inhibited by various deleterious factors bought about by reactions within the injury site. The current forefront of spinal cord repair is in gene therapy (using stem cells) but this is currently prohibited by law in some countries and in particular the United States. Spinal cord regeneration research has followed a multi faceted approach and a number of avenues are being pursued.

Could it be assumed that the plasticity of the human spinal cord (in vivo) could be beneficially affected by microgravity? Considering the findings of some current research it could be assumed that it might [References 53, 54]. Would any change be profound enough to allow a return in sensation or voluntary movement? Well, of course that's unknown and subjectively is unlikely; but considering some advances that have been made and notes given in the abstract "Gravitational neuromorphology" this is certainly an area worth investigating. Knowledge gained, however small, will have a great benefit on spinal cord reconstruction research.

11. Sleep disorder

Disturbances to sleep patterns are undergone by persons with spinal cord injury [References 55, 56, 57] as well as by persons inhabiting a microgravity environment [References 58, 59]. The two may not necessarily be the same, but the effect has a similar meaning. An outline is given here.

Sleep disorder in spaceflight appears to be contributed towards by changes in physiology: If some (or all / most?) of these changes may be lesser in human SCI spaceflight, then it could be assumed that a paralysed and chronically immobile person may suffer fewer acute and deleterious influences on sleep. Second to this, but perhaps more profoundly, if persons with spinal cord injury are used to disrupted sleep patterns they may well be better accustomed to sleep disturbance arising in spaceflight. Presumably, only experience will tell.

12. Activities of Daily Living in Spaceflight with Spinal Cord Injury

Of course, this can only be subjective; and is almost entirely drawn from anecdotal evidence that surrounds myself in every day life. Please refer to the suggested readings for a rounder picture of how spinal cord injury of other levels of injury and "completeness" can have a place in microgravity

Many injuries below the level of C6 and lesser than complete would have independent mobility in microgravity, though some may need assistance with personal care routines. I'm going to concentrate on paraplegia; and if any applying tetraplegic demonstrates complete independence then they also would be just as capable; though they may need adaptations to equipment to enable *functional* dexterity.

12.1 Mobility

Any paraplegic, of capable fitness, build and motivation would (I believe) be fully independent and capable in microgravity. Problems with mobility associated with the lack of verticality would be removed but new mobility skills would have to be learned as with any able-bodied person in microgravity. This should not present any problem: Active wheelchair users learn skills of upper limb mobility above that of propelling a wheelchair. Transfers are the first. By that is meant moving (more dramatically, *shifting*) themselves onto and off the bed, sofa, toilet, car and even the floor. All these transfers require an awareness of how the body moves and turns by moments induced by the upper limbs and shoulders. Further more, the paraplegic well know where they will "land" and how to control momentum in a body and legs they cannot feel. Skills are also learnt in how to propel themselves (in the wheelchair) from one room to another without touching the wheels. This is particularly useful when carrying drinks, especially hot ones; even though as a matter of course the carrying of hot drinks without using non-spill a tray and non-slip mat is discouraged by rehabilitation therapists. As usual, normal life takes over.

These skills will give the paraplegic some preparedness in how to move through voids in microgravity, and sometimes contort themselves into confined spaces (without the usual assistance of gravity) by pushing themselves off solid surfaces. As mentioned earlier (in "Muscle Degeneration) a "former" may help in maintaining good posture, but this should have dampened articulations to counter spasticity and still allow for ease of mobility.

However, gaining access to the launch vehicle may propose a differing set of problems: There will be no wheelchair access and it couldn't be expected to provide any wheelchair access to such an exceptional, and expensive existing design. In many instances, where transfers are awkward or near impossible different mechanisms are used. The primary technique is known as a "Standing Transfer". This is where the paraplegic (and also, and even more usually the tetraplegic) person is stood up by being manhandled about the waistband (or hips / backside) and shoulders with their feet firmly placed on the ground towards the assistant and lifted towards a vertical position; usually turned to the side and then lowered back down to the seat being transferred into[12]. This is an easy procedure when practiced by an assistant. The secondary technique involves the use of sliding boards. Using a sliding board the spinal cord injured person can transfer across large gaps in a series of mini transfers. The third technique is most often used in the severest levels, or in the more acute phase of injury, and involves using a seat-sling and hoist. By using a combination of these techniques and some thought and practice a suitably safe (safe for the vehicle as well as for the people involved in the manoeuvre) can, I'm sure, be worked out. It isn't that long ago that getting into an aeroplane seat for a long haul flight was deemed impossible or impractical and even I've been impressed by the skill and knowledge of some airline and ground crew staff.

12.2 Personal care routines

The paralysed human bladder usually has a volume threshold at which a reflex contraction is stimulated, the sphincter at the neck of the bladder will open and the bladder will empty or partialy empty. Sometimes complete bladder incontinence is induced to improve bladder emptying function: This is usually when the bladder does not completely empty normally or when bladder pressures get too high and reflux to the kidneys becomes a risk. This is when, and how, the suitability of sheath drainage, indwelling / suprapubic or self intermittent catheterisation is adjudged in the first instance, and finally to patient preference. A completely dry routine (excepting with urinary tract infection) is most often if not always maintained.

But, in the absence of gravity, how will fluid be allowed to drain out or away? Well, that would depend on the bladder. There could be enough pressure to create a flow, but probably not to completely empty the bladder or maintain a non-return flow. If there isn't enough pressure a weak pump may be required. Simply connected in-line with the catheter or sheath it could either be automatic or in the case of self intermittent catheterisation be hand operated

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[12] Please refer to "ABC of Spinal Cord Injury" for further clarification.

much like a photographic shutter release bulb and shouldn't be powerful enough or be operated at the wrong time so as to cause damage to soft tissue. Fluid would drain into a bag as is usual. Modern sheath drainage isn't all that advanced; and this improved devices could be commercially exploited.

Exercising a clean bowel routine with paraplegia in microgravity may appear to propose some problems, but in fact it shouldn't. Earliest pioneers of space were presented with some fairly curious obstacles in this matter: Both intrusive and personally difficult. Rehabilitation therapy for paralysis due to spinal cord injury involves a great deal of training. A rehabilitated paraplegic will have learnt routines that maintain an acceptable quality of life. Some of these may involve paying regard to diet and possible use of suppositories; but most importantly *routine*. With some patients, gravity and downward motion may play a part but the spinal cord injured bowel will still maintain at least some peristalsis. Some SCI persons have to exercise a manual bowel evacuation: That would mean that either type of chronic SCI model would be well used to handling solids and / or digital stimulation. Familiarisation with these practices would be an advantage. Personally, I don't envisage much change if any change at all to these practices in microgravity; but it would be advantageous to not have to use suppositories (especially glycerin) and the reasons for that are fairly self explanatory if it's remembered that SCI persons have no control *per se*, or sensation.

In order to ascertain any extra prerequisites for satisfactory bowel and bladder function in microgravity, I would suggest that sub-orbital parabolic flight is experienced whilst exercising established routines.

12.3 Escape

Emergency escape is a consideration that cannot be ignored: Emergency escape from microgravity would involve the use of an escape vehicle, so established functions in mobility would play their part in that. Emergency escape from a launch vehicle would involve parachute and freefall skills. So really were talking about paraplegic solo freefall. That proposition has been met, on enquiry, with cries of "Impossible!", "A complete madness!" Many right minded individuals would agree. Well, they happen to be wrong: Despite my feeling that leaping out of a perfectly serviceable aircraft might seem a silly thing to do; some people do it for fun. (Skydiving is a sport that was enjoyed 3.4 million times in the USA in 1999. - National Geographic). Escape from a fast moving aircraft in terminal distress must remain an option. Paraplegic solo freefall IS possible, and it HAS been done. There are dangers, and technically it does require some readjustment and redesign of equipment, but we're all fairly familiar with that concept.

Eight years ago a gentleman by the name of Adrian Mills, a skydiving instructor and veteran of 1000 freefalls and "countless" base jumps, was seriously injured in a training accident rescuing a pupil. Both survived, but Adrian was left paraplegic. On the anniversary of his injury he took up the challenge and in two weeks, after 1 week in vertical wind tunnel training successfully completed 7 solo freefalls, including satisfactory formation skydiving. SOLO NOT TANDEM he flew his way into another stunning achievement, which was left unrecognised: Guinness Book of Records said it regarded the first, and to date only, paraplegic solo skydive as not being a record, as disability is disregarded in human achievement. (At the time.)

In practice for paraplegic solo skydiving the best possible positions during freefall were experimented with, varying from standing to seated (From which the more contemporary sport of sky-surfing stemmed). It was discovered (in emergency conditions at least) that the natural position in freefall is on the back and that the best positioning of the parachute rig is on the belly. The legs are best stabilised not by suiting them together in a "mermaid suit" but by linking the ankles together (Figure 4) and letting the knees splay out. The knees were bandaged to prevent dislocation. Netting was stitched to the suit in-between the legs (Figure 5) to prevent drone, main or reserve 'chutes from entanglement; and this helped to maintain a more stable, balanced and safe airflow.

Figure 4. Going solo

Figure 5. Showing netting

Note thigh muscle bulk compared to upper arm muscle bulk and the link holding the ankles together, visible in Figure 4. The netting is just visible in Figure 5 (Mills is top right).

In all 7 solo freefalls Mills was able to maintain a stable and controlled enough descent all the way to the ground and in all but one, accurately enough to be caught by handlers rather than landing awkwardly on his paralysed legs. However, in talking with Adrian I understood that a "Flash Cushion", much like a driver's airbag, together with draw strings to raise the legs to a crouch would make solo landings safer and more controllable. With these in place the only assistance required for repeated jumps for an experienced paraplegic skydiver would be in getting into the aircraft, and not even out of it. (Besides having someone fetch the wheelchair, of course.)

Despite the lack of recognition Adrian Mills proved that solo disabled parachute freefall is possible and enjoyable; and that it is possible to safely meet his wheelchair on the ground.

13. Spinal Cord Injury: The next spaceflight revolution

As best as I can, and not being a qualified physician but being a patient, I've tried to give a brief overview of the most immediately obvious factors that should be considered in SCI spaceflight. There are of course extensive varieties of considerations that must be examined and taken into account on this subject, but this paper and the papers it refers to provide a starting point to lead into those avenues.

For a human paralysed subject to be chosen for spaceflight some of the extra qualifying criteria assumed by this paper; in a first study of spinal cord injury paralysis in microgravity should be:-

- A stabilised bone density in the paralysed parts of the body and limbs.
- A stabilised muscle bulk in the paralysed parts of the body and limbs.
- A level of spasticity that is not likely to cause injury or damage.
- Medication that does not include pharmaceuticals likely to under go an adverse change in effect in microgravity.
- A satisfactory (dry / clean) bladder / bowel self care routine.
- Good upper mobility and transfer skills

Many aspects of (disability including) chronic immobilisation (such as SCI there are others...) and of human spaceflight have benefits that could be gained from human SCI spaceflight. As the researcher starts to study this area more fascinations come to light: There are many answers, the questions and (answers to which) will become clearer as this area is investigated.

But with the factors I've introduced, and those that arise from them, it soon becomes an exciting and urgent research project with seemingly many applications for terrestrial and extraterrestrial human research. Chronic immobility and long-term spaceflight result in very similar physiological changes in humans. *VERY SIMILAR, NOT THE SAME*: so by working out what the differences are, and analysing the data; these conditions can be better understood.

With the outline of information I have sourced and provided it is my belief that spinal cord injury Paralysed subjects may be better suited to the microgravity environment and a study may provide a better understanding of:-

- How the mechanisms behind osteoporosis are altered and influenced by microgravity, separate from immobility. How osteporosis may or may not be increased by the further negative influences of microgravity separate to immobility.
- How muscle atrophy is affected by microgravity, chronic disuse, exercise and changes in metabolism. How chronic muscle atrophy may or may not be increased by the further negative influences of microgravity.
- How the cardiovascular and pulmonary system is influenced by microgravity in the chronic state of immobility, what benefits might arise. What effect microgravity has on circulatory function beyond immobilisation.
- How degenerated muscle bulk influences vascular flow in microgravity.
- Sleep disorder.
- Whether or not there are further physiological changes to be undergone in microgravity from the chronic state of immobility as a result of any further bone and muscle degeneration despite microgravity.
- Whether or not the spinal cord injured are better suited to long term spaceflight than the more able-bodied.
- Environmental and sociological aspects of physical disability.

It is the conclusion and challenge of this paper that the human spinal cord injured model may well be better suited to long term spaceflight. There are aspects of the paralysed condition that may have advantages over able-bodied spaceflight; and the earthbound "disabled" may no longer have such a disability, but a greater ability. Further more; sociologically, if we realise that mobility scores are near enough equalised by this (microgravity) change in environment; we will better understand that the concept of physical disability is often a product of our own annealed environment than by the physiological condition itself. These are profound concepts to understand. Human activity in space, both before during and after The International Space Station provides a common equality and meaning for all of us, and there will one day be no exceptions.

Considering current plans for human exploration of Mars, and the subjective 2 year journey in microgravity this would imply it is certainly now worth researching the efficacy of sending a person with chronic immobility (and suggestively initially high thoracic spinal cord injury) on this next sojourn: By opening up new horizons, by extending human presence and knowledge many surprises are in store for all of mankind, and microgravity ability would perhaps have the profoundest of meanings.

14. Study aids

All the references have been deliberately chosen from one individual internet site to enable the reader quick and easy reference to them The site is operated by the United States' National Library of Medicine "National Center for Biotechnology Information" at **http://www.ncbi.nlm.nih.gov.** using their PubMed search engine, with "limits" you can quickly access the referenced abstracts and order full copies of the papers. Sadly, intellectual property rights prohibit me from reproducing the abstracts in full: Please take the time to download them and explore PubMed further by making use of Table 1 below.

R#	Abstract title	PubMed ID
1	Continuous loss of bone during chronic immobilization: a monozygotic twin study	10501792
2	Longitudinal study of bone mineral content in the lumbar spine, the forearm and the lower extremities after spinal cord injury	2114994
3	Bone mineral density differences between paraplegic and quadriplegic patients: a cross-sectional study	10369173
4	Calcium balance in paraplegic patients: influence of injury duration and ambulation	718407
5	Increased serum osteocalcin levels in patients with paraplegia	1630849
6	Effects of long-term microgravity exposure on cancellous and cortical weight-bearing bones of cosmonauts	10821365
7	Space flight and the skeleton: lessons for the earthbound	11540416
8	Musculoskeletal adaptation to mechanical forces on Earth and in space	11537418
9	Future human bone research in space	9600765
10	Lower limb skeletal muscle function after 6 wk of bed rest	9029214
11	Influence of complete spinal cord injury on skeletal muscle mechanics within the first 6 months of injury	10552277
12	Lower extremity manifestations of spasticity in chronic spinal cord injury	2917056
13	Phenotypic adaptations in human muscle fibers 6 and 24 wk after spinal cord injury	11744654
14	Scientific basis of spasticity: insights from a laboratory model	112252952
15	Treatment of Spasticity in Spinal Cord Injury with Dronabinol, a Tetrahydrocannabinol Derivative	11854790
16	Botulinum neurotoxin intramuscular chemodenervation	11723867
17	Muscle volume, MRI relaxation times (T2), and body composition after spaceflight	11090562
18	Functional and structural adaptations of skeletal muscle to microgravity	11581335
19	Sensorimotor adaptations to microgravity in humans	11581337

20	Temporal control and motor control: two functional modules which may be influenced differently under microgravity	11543514
21	Research on the adaptation of skeletal muscle to hypogravity: past and future directions	11542447
22	Limb blood flow, cardiac output and quadriceps muscle bulk following spinal cord injury and the effect of training for the Odstock functional electrical stimulation standing system	8332376
23	Cardiac output during exercise in paraplegic subjects	2044535
24	Cardiorespiratory fitness and training in quadriplegics and paraplegics	3529281
25	Cardiovascular responses during arm exercise and orthostatic challenge in individuals with paraplegia	11513326
26	Mechanisms of thrombosis in spinal cord injury	10806563
27	Cardiac atrophy after bed rest and spaceflight	11457776
28	Fluid volume control during short-term space flight and implications for human performance	11581336
29	Central venous pressure and cardiac function during spaceflight	9688754
30	Autonomic regulation of circulation and cardiac contractility during a 14 month space flight	11541600
31	Lung mechanics in individuals with spinal cord injury: effects of injury level and posture	11160035
32	Breathlessness and exercise in spinal cord injury	10751134
33	Maximal exercise in spinal cord injured subjects: effects of an antigravity suit	11541516
34	Cardiopulmonary adaptation to weightlessness	11538737
35	Effect of microgravity on the respiratory system	1864769
36	Respiratory mechanics after 180 days space mission	11541602
37	The effects of autonomic dysfunction and endurance training on cardiovascular control	11503947
38	Regulation of autonomic nervous system in space and magnetic storms	11541400
39	Metabolic changes in persons after spinal cord	10680161
40	Changes in thyroid hormones, thyroid stimulating hormone and cortisol in acute spinal cord injury	1635789
41	Influences on renal function in chronic spinal cord injured patients	11025689
42	Level of injury and hormone profiles in spinal cord-injured men	11711334
43	Mineral metabolism in spinal cord injury	7369852
44	Pituitary-testicular and pituitary-thyroid axes in spinal cord-injured males	8487676
45	The hypothalamus-pituitary-ovary and hypothalamus-pituitary-thyroid axes in spinal cord-injured women	8637446
46	Monitoring of renal function in patients with spinal cord injury	10848686
47	Renal and bladder functions in patients after spinal cord injuries	7939462
48	Physiological changes in spaceflight that may affect drug action	11543004
49	Hormonal changes in humans during spaceflight	10660774
50	Space flight and the risk of renal stones	11543039
51	Human spinal cord retains substantial structural mass in chronic stages after injury	10391368
52	Spinal cord injury repair research: a new combination treatment strategy	11699192
53	How the science and engineering of spaceflight contribute to understanding the plasticity of spinal cord injury	11543389
54	Gravitational neuromorphology	7757255

55	Sleep apnea syndrome in chronic spinal cord injury: associated factors and treatment	11030498
56	Sleep disturbances in the spinal cord injured: an epidemiological questionnaire investigation, including a normal population	11641793
57	Obstructive sleep apneas in relation to severity of cervical spinal cord injury	9773446
58	Sleep-wake differences in scaling behavior of the human heartbeat: analysis of terrestrial and long-term space flight data	11542917
59	Sleep, performance, circadian rhythms and light-dark cycles during two space shuttle flights	11641138

Table 1. Referenced National Library of Medicine PubMed ID numbers

For further information a list of internet sites below can be followed: These will provide links to how to order suggested readings; and links to other relevant resources. The link to ERISTO can be found on the Institute for Space Medicine and Physiology's homepage under "Osteoporosis".

Organisation	Homepage
British Association of Spinal Cord Injury Specialists	www.bascis.pwp.blueyonder.co.uk/
The Spinal Injuries Association (UK)	www.spinal.co.uk/
The International Spinal Research Trust	www.spinal-research.org/
Institute for Space Medicine and Physiology	www.medes.fr/Home.html
British Medical Journal	www.bmj.com/
National Library of Medicine	www.ncbi.nlm.nih.gov/

Table 2. Useful links

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