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Monitoring and telemedicine support in remote environments and in human space flight

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The common features of remote environments are geographical separation, logistic problems with health care delivery and with patient retrieval, extreme natural conditions, artificial environment, or combination of all. The exposure can have adverse effects on patients' physiology, on care providers' performance and on hardware functionality. The time to definite treatment may vary between hours as in orbital space flight, days for remote exploratory camp, weeks for polar bases and months to years for interplanetary exploration. The generic system architecture, used in any telematic support, consists of data acquisition, data-processing and storage, telecommunications links, decision-making facilities and the means of command execution. At the present level of technology, a simple data transfer and two-way voice communication could be established from any place on the earth, but the current use of mobile communication technologies for telemedicine applications is still low, either for logistic, economic and political reasons, or because of limited knowledge about the available technology and procedures. Criteria for selection of portable telemedicine terminals in remote terrestrial places, characteristics of currently available mobile telecommunication systems, and the concept of integrated monitoring of physiological and environmental parameters are mentioned in the first section of this paper. The second part describes some aspects of emergency medical support in human orbital spaceflight, the limits of telemedicine support in near-Earth space environment and mentions some open issues related to long-term exploratory missions beyond the low Earth orbit.

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The architecture of telematic support

The main system components for remote tele-assistance are peripheral data sources, on-site processing and storage units, telecommunication links and dispatch facilities. The strategy (evacuate *vs* treat on site) will depend on available resources and the final outcome will be determined by the quality of assistance networks. Some of the important factors are: Quality of status monitoring on-site, especially detection of anomaly and alarm acknowledgement; on-site limitations in technology and in human performance; possibilities of support via telecommunication links; logistic aspects of patient transportation; total elapsed time from the emergency event to the definite treatment; and the risk exposure for the victims and for the recovery teams.

The signals, which are typically acquired and transmitted, can be simple data (temperature, position, pulse oximetry), audio (voice command, electronic stethoscope), still or moving images (text, graphics files, videoconference), or a combination of all the above.

There are different levels of interactivity between the peripheral and consulting site:

- One-way telemetry, for example wind velocity, heart rate.
- Telemetry with command, for example spacecraft trajectory adjustment, remote consultation.
- Interactive control, for example industrial processes, remotely manipulated procedures.
- Autonomous operation with on-site decision, where only initial- and end-status are transmitted, for example space exploration, future medical systems.

Sensors

The minimal 'on the move monitoring' requirement would be a registration of selected physiological and environmental data, of movement patterns in a three-dimensional environment including the instant position, and of trends for all these parameters. Evaluation of isolated physiological parameters has only limited diagnostic and prognostic

value, for example the heart rate of fire-fighters will be influenced by the physical activity, type of protective garment, temperature, level of psychical stress or the ambient atmosphere. Some medically relevant parameters that is temperature, humidity, position, acceleration, barometric pressure or atmospheric composition can be easily measured by standard, cheap industrial sensors, which are resilient to the physical environment.

Different sensor systems are being deployed around the world to monitor the natural environment, or technological processes. Traditionally, these tend to be domain-specific and to use proprietary data formats. A new instrument concept, called 'sensor web' has been introduced recently. Sensor webs can essentially be viewed as networks of smart sensors, as a macro-instrument or a single *distributed* instrument. Data collected by the macro-instrument is sent to a collection point, a server, which reads, processes and stores these data. Two-way communication would typically exist to command and control the sensor web, to set event monitoring, to change sampling schedules or verify status of the sensor web. Sensor webs are characterized by their ability to share the information between sensing nodes and to modify their behaviour on the basis of the acquired data. They are scaleable, autonomous and comparatively cheap. Their main applications have been in the environmental monitoring and the full potential for medical applications is to be evaluated. This concept would be well suited for integrated monitoring of environmental and physiological parameters, where the aim is to keep the single individuals or groups within defined performance envelopes and to recognize potentially dangerous trends before the off-nominal threshold is reached. The monitoring must be non-intrusive to be accepted by the users, for example wearable devices or remote acquisition of physiological data.

Peripheral sites

The monitoring systems can be integrated in with other diagnostic devices, for example videoscopes, in 'all-in one' dedicated telemedicine unit (e.g. Telemedicine Instrumentation Pack, Wyle Lab, Houston). These sophisticated and compact devices are limited to one specific application.

The open, multi-purpose systems, compatible with different stand-alone peripheral devices, are suitable when telemedicine is only one part of the overall telematic support. They are more resilient to system failure and can be cost effective. Wireless connections between system components are preferable, especially in confined environments. Many medical devices are certified for outdoor use, but the performance in the real environmental conditions is often not satisfactory. Power failures and fading of the display screen are common problems in cold temperatures. Resilience to motion artifacts is essential in any mobile environment; electromagnetic interference, compatibility with artificial atmospheres, or aircraft/spacecraft specific constraints must be considered. Any modern monitor should be compatible with the telecommunication equipment.

Mobile telecommunication devices

Telemedicine is not a product of the information technology era. Distant medical advisory, based on radio contact, or on messages in Morse-code, worked quite well for most of the last century and a two-way voice communication at fairly low bandwidth remains a backbone of any telemedicine consultation. The majority of telemedicine data is nowadays transmitted through terrestrial digital and analogue telephone networks or global system mobile (GSM), either directly or via Internet and the remote sites usually rely on satellite links. High frequency (HF) radio is still available and used worldwide in the commercial aviation, at high seas, in many developing countries and in the radio-amateur community, the very high frequency (VHF) links are widely used in the coordination of local teams.

Important parameters to be considered in the selection of communication system for telemedicine are:

- coverage requirements: local, regional, global;
- availability: permanent or temporal;
- modus and urgency of information transfer: real-time, store-and-forward;
- minimal and maximal up-link/down-link bandwidths;
- transmission protocols and compatibility with multiple senders/receivers;
- data encryption and safety;
- cost per equivalent amount of transmitted information;
- overall system costs, that is purchase and cost of telecom traffic.

The mobile satellite communication terminals can be conveniently classified according to their operational bandwidth, being low, medium or high bandwidth.

Low bandwidth, highly portable 'pocket-size' systems in the range 2.4–9.6 kps suitable for the transmission of voice and data in real time, or for transmission of files in store-and-forward mode. They can be connected to small sensors or personal medical devices and would handle the transmission of a simple 1- or 3-lead ECG, HF, BP, T and Sa_{O_2} if the medical devices are equipped with appropriate interfaces. Signal transmission is through satellites in geostationary orbit (Inmarsat Mini, Thuraya) or through the low-Earth-orbit satellite constellations (Iridium, Globalstar). Thuraya, Iridium and Globalstar use small omni-directional antennas; this and their comparatively small size make them suitable for the monitoring on the move. The global coverage, including both poles, is possible only with iridium. These systems are suitable for emergency applications, for monitoring in exploratory settings and for surveillance of persons with specific risks or needs. Some satellite telephones in this category can switch to GSM mode.

Medium bandwidth, 'backpack size' systems are scaleable in the range of approximately 64–400 kps. In addition

to the capabilities above, they will handle a real-time, two-way videoconferencing and multiple channel monitoring at high sampling rates. These systems typically support emergency medical teams, or small clinical outposts, such as military operations, exploratory sites, or remote mining camps. They all communicate through geostationary satellites and use laptop-size directional antennas, oriented towards the specific satellite. Tracking antennas maintain constant azimuth and elevation angles to the satellite and are used for transmission from moving targets, such as vehicles, aircraft and ships at sea. The geostationary satellites are positioned above the equator, 40 000 km from the earth's centre, and because of their orbital geometry cannot cover the high polar regions. The guaranteed geographical coverage of geostationary systems is approximately 70° S to N latitude. (The practical range is somewhat better, especially if the ground station is at a higher elevation above the ground. The Antarctic stations are mainly located along the coast of the continent, which lies within the coverage of geostationary satellites. Some stations in the interior (e.g. Russian Vostok at 78.4° South and 3420 m elevation), can still communicate through geostationary systems. A broadband transmission from the South Pole is intermittently possible because of the fact that the geostationary satellites towards the end of their orbital life cannot maintain their exact orbital slot and wobble towards both poles.)

A typical example is Inmarsat B. The whole telemedicine installation in Satellite-ISDN (Integrated Services Digital Network) mode can be made operational within minutes. The recently introduced Inmarsat BGAN (M4) generation uses IP protocol for data transfer and its potential for telematic support is being evaluated. Satellite modems are typically connected to videoconferencing and data-processing terminals (7E, Tandberg Tactical, Scotty Mobile, etc.); their performance spans from simple one-channel videoconferencing to simultaneous transmission from different inputs with dynamic bandwidth adjustment, MPEG file creation and other features. These systems are workhorses in mobile broadcasting, in emergency technical repairs, in disaster relief operations and in field medical support. We consider the transmission bandwidth of 128 kps (equivalent of 2x ISDN, or 2x Inmarsat B link) sufficient for most telemedicine applications, including remote tele-consultation and procedure supervision. Our systems routinely use two peripheral video inputs, the first (preferably remotely controlled from the consulting site) is used for a synoptic situation view, the second can be detail investigation camera or signal output from endoscopes, sonography probes, etc. (Fig. 1).

High bandwidth, 'small truck size', use highly accurately pointed directional dish antennas and communicate through geostationary satellites with bandwidth in the Mps range; they will support practically any telemedicine application. In addition to the performance of all systems above, they are suitable for interactive procedures in real time. They are typically deployed at permanent or semi-permanent installations such as big oil rigs, remote mining sites or field hospitals, where a large amount of telecommunication traffic over several weeks or months is expected. The system installation is time consuming and therefore not suitable in a real emergency.

Fig 1 A typical portable broadband telecommunication system in the field. Left: data acquisition part (e.g. document camera, endoscope, ECG); middle: videoconferencing, data storage and processing device (Scotty Mobile); right: satellite modem with antenna. The communication is through Inmarsat geostationary satellite, minimal bandwidth is 64 kps. (Scotty Group Inc., Graz, Austria, FS Communication, Effretikon, Switzerland and Applied Space Technology, Lachen Switzerland.)

The delay in satellite-based communication between two terrestrial sites depends on the exact transmission path between the satellites and the ground stations. It typically does not exceed 1 s in a single-hop link. This is acceptable for any form of tele-consultation, but limits the feasibility of some remote manipulation procedures with feedback. Tracking and location devices are important components of any telematic support. The satellite-based systems (e.g. Argos, Glonass, GPS) have global coverage; low-range radiofrequency devices are sometimes used for local search and rescue operations, for example avalanches.

Dispatch and consulting sites

Well-qualified dispatch and consulting personnel are crucial to the success of any tele-assistance. The medical knowledge and skills of care provider at the remote sites will be typically either general or very limited and tele-support protocols must be adapted to this (language, terminology, speed of procedures). Modern telemedicine-enabled monitors are usually equipped with automated voice guidance through the whole set-up; this is very helpful, especially if the care provider has to manage multiple tasks simultaneously. Standard operational procedure for telematic support in specific settings should be developed and validated on simulators; certification of system architectures and of providers' proficiency may become compulsory in the future. Vital data monitors in dedicated telemedicine systems are usually connected to the

telecommunication equipment and the transmission occurs through defined protocols. In an emergency, or when using *ad hoc* available equipment, 'video-only' telemedicine session may be the only practicable solution. A camera view, showing the overall situation, the patient and the monitors is surprisingly helpful and the live video contact has positive psychological effect on the crew at the peripheral site.

Contrary to popular belief, telemedicine is not the first priority in immediate treatment in disasters, especially in remote areas. Situation assessment and co-ordinated action planning have to be done first and local medical teams are often easier to obtain than telemedicine equipment. However, information technologies are helpful in triage, victim location and in the establishment of relief structures. High costs of satellite telecommunication traffic, limited experience and legal constraints in some countries are frequent obstacles in the implementation of mobile telemedicine systems.

Monitoring and telemedicine in human spaceflight—the environment

The main difference between the terrestrial and space-borne medical care is the altered gravitational environment. The absence of gravity influences common physical processes: sedimentation of particles does not occur, properties of fluid–gas interfaces change, absence of convection affects gas and fluids mixing, gravity-dependent devices (e.g. conventional anaesthesia valves or flow-meters) will not work, force-generating medical procedures require restraint, etc. Compared with this, the effects of sustained acceleration during take-off and landing phases are relatively minor. All spacecraft are closed-circuit environments and contamination of habitat atmosphere must be avoided. Some aspects of space environment, can be simulated on the earth, for example isolation in closed-circuit habitats, sustained acceleration, short duration microgravity in parabolic flights or in neutral buoyancy labs or bed-rest studies. Experiences from analogous terrestrial environments are used for procedure design and in psychological investigations. However, the prolonged exposure to microgravity or partial gravity (Moon 0.16 g, Mars 0.38 g), the psychological effects of remoteness and the interplanetary radiation exposure cannot be simulated.

The physiological response to spaceflight depends on flight duration. Short missions are characterized by adaptive changes in immediate response to micro-*g*, such as fluid shifts in cranial direction, space motion sickness, fatigue, sleep disorders, etc. In long-duration flights, the structural and degenerative changes, for example muscle atrophy, bone de-mineralization, reduced immune response, decreased circulating volume, etc. are more important. Re-adaptation to 1 *g* environment after flights of several days is fairly rapid; the post-flight orthostatic intolerance and neuro-vestibular symptoms are mostly transient. The degenerative changes, associated with long flights, are more serious and re-adaptation to 1 *g* takes longer, for example restoring of the original bone density may last years after very long microgravity exposures. (Crewmembers of long-duration flights are typically unable to walk unassisted on the earth immediately after landing.) The longest continuous microgravity exposure for a single person (V. Polyakov, Russia) was 438 days and direct data about effects of longer microgravity or partial gravity exposures do not exist. Active and passive countermeasures, are administered in-flight to alleviate the effects of microgravity (bicycle ergometers, treadmills, 'penguin suits', low body negative pressure device, fluid loading). They are sufficient for the current International Space Station (ISS) operations, but would have to be re-designed for long-time exploratory missions, possibly including the application of artificial gravity onboard the spacecraft.

Origin of monitoring in spaceflight

Monitoring of humans in space started with the first manned flight of Yuri Gagarin, April 12, 1961; but the first telemetry of vital data from spaceflight was successfully demonstrated 2–3 yr earlier on dogs (Russia) and monkeys (USA). Because of many unknowns at that time, especially reactions of cardiovascular system in response to microgravity and psychological effects of orbital flight, Gagarin was monitored with continuous transmission of heart rate, ECG and ventilatory frequency, EMG electro-oculogram, thermography and galvanic skin response. Vital data in the early Russian and US space programmes (Vostok, Voschod, Mercury, Gemini) were typically transferred by one-way telemetry downlink. Serious medical events were not anticipated during short flights with crew of one or two extremely fit crewmembers and any medical handling inside the spacecraft would have been very difficult or impossible anyway.

The capability of onboard medical diagnostics and treatment became an operational requirement for long-duration missions with multiple crew in bigger spacecraft or in orbital stations (Soyuz-Salyut, Skylab, Mir, Space Shuttle, ISS). Physiological data are collected during scheduled medical checks, before and during extravehicular activities (EVA) or as diagnostic tool in medical emergencies. Specific datasets exist from scientific experiments, mostly investigations of locomotion, cardiovascular and neuro-vestibular systems. Sonography in spaceflight was first performed in the Soviet programme in the 1980s by Atkov and colleagues in Solyut orbital complex; in 2004 Foale and colleagues evaluated the diagnostic capabilities of ultrasound investigation onboard the ISS and tested the remote guidance via telemedicine link. The early monitoring and diagnostic devices were often custom-built for the spaceflight; the recent trend is towards adaptation and space-certification of commercially available hardware. Continuous monitoring of space crew is not practised today and, after 45 yr of human spaceflight, the basic physiological data are still scattered between different institutions in various formats. Small size of data samples,

and lack of validation models make the modelling of the space physiology on Human Patient Simulators difficult.

Emergency medical care in orbital spaceflight

There were four fatal accidents in the space flight. The US programme lost two Shuttle orbiters because of structural disintegration (one during take-off, one during atmospheric re-entry), with a total of 14 fatalities. The former USSR had two re-entry accidents (landing parachutes malfunction, loss of cabin pressure) with a total loss of four lives. Both space programmes had several near-misses (e.g. Apollo 13, fire on second German Mir mission). The acute medical problems in space, such as therapy resistant arrhythmia, infection, toxic exposure or trauma, were up to now solved by on-site treatment, or by prophylactic de-orbit of the sick crewmember. With increase of human/hours in space and less stringent criteria for crew selection, including space tourism, medical problems can be expected in the future. For the crew of six, both Russian and US programmes estimate the frequency of emergency treatment in space as approximately once a year. Advanced life support (ALS) and/or anaesthesia, would be required once in 3–4 yr.

A real experience with basic life support (BLS) and ALS in microgravity does not exist. Apart from surgery on experimental animals in orbit, the emergency medical procedures were only simulated in mock-ups, centrifuges and in parabolic flight, but inherent limits of these simulations are short, 20–25 s microgravity periods, alternating with 2 *g* acceleration as the aircraft follows the parabolic flight path. Different methods for performing chest compressions were tested, including CPR on a 'free-floating' patient, but it is unlikely that an efficient mechanical CPR can be performed over longer periods in microgravity or in partial gravity with presently recommended terrestrial methods. Airway management by conventional means [mask and bag, tracheal tube, laryngeal mask airway (LMA)[†]] have been tested by several investigators, the average times to secure an airway in microgravity were longer in comparison with 1 *g* for both skilled and unskilled operators, but all procedures are technically possible. The use of intubation-LMA is currently recommended for the ISS. Restraint of the provider and the patient is essential with any force-generating procedure and any released organic material must be collected to avoid a contamination of the closed-circuit habitat. The feasibility of space-specific BLS/ALS procedures is presently investigated by several research groups among the ISS partners (Fig. 2).

Fig 2 Testing different telemedicine architectures in the mock-up of the ISS in the Gagarin Cosmonaut Training Centre, Star City, Russia. Courtesy of 'Telemedicine Assistance Onboard the Russian Segment of International Space Station', DLR Project Nr WB 0148.

Operational aspects of ALS procedures

The strategy for emergency treatment in orbital spaceflight is similar to other remote environments: stabilization and evacuation if necessary. There is neither an objective need to perform complex medical procedures, nor are the resources for such procedures available, but provision of ALS on board the orbital stations has several limitations. The treatment would absorb most of the human resources in the small crew. Medical emergency can be a consequence of severe spacecraft malfunction; in such a case, the repairs would be an immediate survival priority, and the evacuation of the whole crew might be required. The currently flown Crew Health Care System is not designed for prolonged ALS; the diagnostic and emergency treatment capability corresponds roughly to a good European ambulance. There is seldom a physician on board and the average medical training of crew medical officer is in the order of about 40–60 h. At this level, even when supported by real-time telemedicine link, the quality of treatment in space will never be equivalent to the earth. A new concept 'just-in-time training', is based on the combination of on-site CD ROM tutorials with real time tele-guidance from the ground expert centre and was applied to sonography investigations at the ISS in 2004 with good results. This technique would be also applicable to any other remote setting.

The extravehicular activities (EVA) are associated with additional risks. Any sudden medical event with loss of consciousness in the EVA suit could be very dangerous; the aspiration risk in microgravity is increased and any therapeutic intervention is impossible while outside the spacecraft. The time delay between the medical event and the initiation of treatment would be significant (retrieval of the crewmember, pressure equalization, extraction from the suit, etc.). There is no dedicated facility on board to treat severe decompression trauma. US and Russian EVA suits have different design and are not compatible (Fig. 3).

Evacuation from the orbit

A spacecraft communicates with the Mission Control Centres in Moscow or Houston either through geostationary

[†]LMA® is the property of Intavent Ltd.

Fig 3 Russian ORLAN–DM Spacesuit, used for extravehicular activities (EVA) at the ISS. Courtesy of GCTC Gagarin Cosmonauts' Training Centre, Star City, Russian Federation and DLR Project W 0148. Parameters measured during the EVA are suit environment, with temperature, pressure, O_2, CO_2, ECG, respiration and radiation exposure. They are collected on board the ISS and transmitted to the earth during telecommunication sessions. The atmosphere inside the suit is oxygen at approximately 0.3–0.4 kPa, the ISS operates on normal air at 1.0 kPa.

TDRS system, or through direct downlink to the ground station as the spacecraft passes by. The ground control centres are linked to a network of supporting institutions, which can provide on-demand expert opinion. The telecommunication signal delays within the system are in the order of 2 s, quite acceptable for remotely supervised procedures. Continuous broadband 365/24 telemedicine link from the ISS to both control centres is currently not possible and the sessions are realized during communication windows. The emergency medical transportation to the Earth has the following steps: after the medical assessment and the first stabilization onboard the station, and a decision to de-orbit would be made when necessary; the patient would be transferred into the Soyuz spacecraft and preparations for undocking from the ISS would be made; after the separation from the ISS and after a short waiting time in the orbit, the re-entry of the descent module would be initiated from a specific orbital position, to reach the dedicated landing area; the post-landing crew egress and the extraction of the patient from the descent capsule will be typically assisted by recovery teams; an additional treatment could be administered immediately on the landing site and in a dedicated mobile medical facility, located in the landing area; finally, the patient would be airlifted to the tertiary medical centre.

The only realistic option for emergency evacuation from the ISS is a dedicated spacecraft, which is permanently attached to the station. The Russian Soyuz TMA is presently used for crew transport to the ISS and is also the primary rescue vehicle. Other solutions, such as rescue mission from the earth, or another spacecraft in the tandem orbit, are presently not feasible. The orbital autonomy of Space Shuttle, even if operational, is 14–16 days and it could not be permanently docked to the ISS.

The Soyuz descent module accommodates three crew-members; it was never primarily designed for patient transport under ALS conditions. The currently available crew monitoring is standard telemetry (T, EKG, respiration) and two-way voice communication. Modifications to enhance Soyuz medical capability are being investigated, for example portable ALS platform, mechanical pulmonary ventilation during de-orbit and improved tele-medical support with video-supervision. (Communication with any re-entering spacecraft is temporarily lost when the atmospheric friction heat creates a plasma environment around it.) The spectrum of medical procedures in the descent module is limited by its small size (approximately 2×2 m) by restraint of crew members and of the patient in their lodgements by the manual dexterity in the re-entry suit and by the *g*-forces, which peak at 3.8 *g* during the normal landing profile and can exceed 7 *g* in the emergency ballistic re-entry. During testing in centrifuges, it was shown that the selected new ALS equipment can perform normally in the hyper-gravity, but some mechanical devices, such as Ambu bag, could not be used at high acceleration levels. The nominal ground track of ISS lies between 52° N to S and an emergency landing of Soyuz spacecraft would be technically possible anywhere within this range, but the nominal landing site in Kazachstan would normally be used because of recovery logistics. The presence of recovery teams on the landing site is essential to assist with the egress of de-conditioned crew and to continue the emergency treatment if necessary.

Monitoring and distant care for exploratory space missions

Important differences exist between medical care for orbital flights and for interplanetary missions. The earth's surface is protected from the galactic cosmic rays and from the radiation emanating from the solar events (solar flares and coronary mass ejections) by the atmosphere and by the magnetic field. The radiation exposure at the typical ISS orbital height of 400–500 km is still lower than in the interplanetary environment. Mars has an atmosphere (composed mostly of CO_2, with reference pressure of 6.1 mbar compared with 1013 mbar on the earth), but has no own magnetic field. The moon has neither atmosphere, nor magnetic field, but radiation risk in Moon exploration

could be partly reduced by mission design (shorter duration, timing during low solar activity). The treatment at the lunar base could be supervised in quasi real time and the subsequent evacuation would be faster than from some remote places on the earth, for example from Antarctic bases in the winter. For the exploration of Mars, several scenarios exist, with different duration of stay on the surface and different Earth–Mars transit times. The shortest version exceeds 1 yr, the longest would last almost 3 yr. The abort of the mission after the departure from the earth (e.g. return after 2–3 months in flight) is technically not feasible. Close monitoring of crew physiology, of psychological performance and of radiation exposure en-route and at destination will be essential and the radiation alone, or in combination with reduced immune response, might be the main obstacle to human exploration of Mars. Real-environment radiation data, collected recently by the robotic probes, are now used in exposure modelling and various methods of shielding for the spacecraft and for the ground structures are being investigated.

The distance between Mars and Earth depends on their relative orbital positions and is roughly between 58 000 000 and 400 000 000 km, with signal propagation times approximately 3.5–23 min one-way, or 7–46 min for the round trip. This clearly excludes any real-time interaction or tele-manipulation, but does not affect data transfer in store-and-forward mode. The current strategy for management of emergencies in spaceflight, which relies on the assistance from the ground centres (stabilize–consult–evacuate), would have to shift towards an increased *in situ* autonomy, assisted by extensive onboard medical databases. Virtual reality training for medical and technical skills retention, interactive medical devices with automated diagnostic and advisory features, and intelligent sensor networks to monitor the human–environmental interactions would very likely be used. The probability of medical events could be only partly reduced by crew selection; some prophylactic measures, such as elective appendectomy before the mission, might be considered. The problems of isolation and self-sufficiency are not new; they were typical for the polar expeditions in the 19th and early 20th century, but without advanced monitoring and communication.

It has been demonstrated that diagnostic and therapeutic procedures, including surgery, could be performed in microgravity. An expert opinion would be always possible, except in extreme emergencies. There are no obvious reasons why regional blocks, isobaric spinal anaesthesia, or TIVA should not work in micro- or partial gravity, but unexplained complications of anaesthesia, administered to monkeys immediately after the return from space, have been described. However, the mass and volume of the medical equipment, problems with asepsis and with reduced immune response, unknown reactions of de-conditioned organism to the medical intervention, performance of the local team and risk/benefit calculation must be considered in the design of a remote medical facility. Long-term medical care for seriously impaired crewmembers would be not only an ethical, but also a technical problem. A concept of an automated medical support (‘critical care autopilot’) , would be helpful if patient’s status has to be kept constant under variable conditions, he/she must be left unattended for logistic reasons, severe impairment of crew performance or risk of errors exist, or the decision to be made exceeds the capability of the attending personnel.

The main risks and investigation areas for exploratory class of missions are summarized in NASA Bioastronautics Critical Care Roadmap:

- human adaptation and countermeasures;
- radiation exposure;
- behavioural health and performance;
- human support technologies, especially advanced monitoring;
- distant medical care.

The establishment of the moon base and research in long-duration microgravity exposure are the next logical steps in the human space exploration. The ISS with its current configuration and operational policy has only limited value in microgravity research. The recent developments in telescience and in robotic exploration make it possible to collect the data from the interplanetary environment systematically and comparatively cheap and a careful cost–benefit analysis of human space exploratory missions beyond low Earth orbit is needed.

Conclusion

Coherent monitoring of human physiological parameters and interactions with the environment are essential components of telematic support in remote settings. The telecommunication and navigation infrastructure is the most significant contribution of space industry to the emergency medicine and all major space agencies are currently involved in terrestrial telemedicine applications. The development of future systems will be most probably driven by the users’ needs.

Mobile individuals, small groups in potentially risky environments, or persons with health risks would benefit from non-intrusive, wearable, intelligent monitoring systems. These systems should detect the anomalies, recognize dangerous trends, provide early warning with advisory and connect with assistance networks when necessary.

Groups in remote settings similar to Antarctic bases or exploratory camps with ambulatory care facilities could use the same monitoring systems as above. Their medical capability and occupational safety would be enhanced by tele-presence and remote supervision through broadband audio-visual links with selected networks of consulting institutions.

Extremely remote terrestrial settings or space exploratory missions would require a close monitoring of early

deviations from nominal physiological status, of individual and group behaviour and of human/environment interactions. The on-site decision making would be assisted by intelligent data-processing systems and by remote consultation if appropriate.

The technology for most of these applications is now commercially available. More advanced concepts have been validated in laboratory settings and could become available within the next years. Integrated, user-tailored solutions, might help to reduce costs within the health care sector. Monitoring and telematic systems in some industrial applications are often more advanced than those currently used in medicine. Technology transfer and solution sharing could be a straightforward approach to the implementation of affordable monitoring, not only in distant medical settings, but also in daily health care.

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