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Aspects of Oral Health and Treatment for long-term Human Space Missions with remote support and advanced technology

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Abstract

Health issues of astronauts or cosmonauts are of high importance prior to launch and during the space mission. A wide range of medical examinations are carried out as part of the astronaut selection process and during training to ensure the best possible health status of each crewmember at the time of launch. For treating pain and dysfunction that could occur during a mission, a set of basic medication and medical equipment is available onboard. Astronauts are also trained to handle some of the most likely medical emergencies.

Although occurrences of dental injuries have been minimal so far, they are expected to rise significantly on long-term missions to the Moon, Mars and beyond. Reasons for dental injuries accompanied by severe pain and dysfunction are manifold. A replacement of a lost dental restoration and/or a stabilization of fractured teeth and jaws can be important to prevent further damage to human health, to limit the loss of manpower, and finally to ensure mission success.

As a follow up to the paper: *Dental Treatment during a human Mars Mission*, presented at ICES 2016, the authors outline a possible mission scenario of detecting, diagnosing and treating a dental problem during a human mission. This process includes advanced methods for diagnosis and manufacturing for dental health treatment. Following an introduction and rational for dental health during long-term missions, the authors discuss an exemplary medical case with its operational and technical conditions.

Keywords: Dental Health, 3D printing, Human Factors, Human interface technology

1. Introduction

Major milestones and health issues related to dental experiences were summarized in the preceding paper *Dental Treatment during a human Mars Mission* [1]. In that, it has been shown that the probability of the need of inflight dental treatment increases with the duration of the mission and the number of crewmen.

It is likely that a dental emergency or at least dental caused discomfort will occur during a long-term Mars mission and "*dental emergencies can become true medical emergencies*" [2 p.554], if not properly handled.

Currently no procedure or technology is available to sustain and restore teeth for long-term missions on-board a space station or at a planetary base. On future outbound flights for example to Mars and interstellar travel, all emergencies have to be handled by the crew itself. The previous paper has discussed scientific, technical and operational challenges for dental treatments. This paper goes one step further and discusses the procedure of one case study in detail.

2. Importance of Dental Health for Space Missions

In most parts of the Earth, people would seek help from a dentist, in case they suffer from tooth pain. For low-Earth orbit missions, pain can be suppressed until medical help back on Earth is available.

In contrast to Earth and low-Earth-orbit missions, outer space missions may not have a dentist and dental technician available. It will not be able to evacuate a sick or badly injured crewmember (e.g. fractures of jaw bones and/or teeth by trauma).

Based on this 'problem', the authors have started to think of solutions for the following scenario: *'What would happen, if an astronaut on a long-term outer space mission suffers from dental and/ or jaw problems that cannot be treated sufficiently by pain medication?'*

2.1 Crew conditioning BEFORE and DURING the mission

Currently all astronauts receive pre-flight medical examinations prior to their missions on-board the International Space Station. These examinations include a dental check and pre-flight medical training performed 10 days or less prior to the mission. Two astronauts of each Expedition Crew receive additional training as Crew Medical Officer (CMO). This training includes "*cross training in different disciplines so that they could provide surgical assistance, anesthesia support, and diagnostic capability* […]" [3 p.296]. Inflight, the Crew flight Medical Officer conducts regular medical examinations as well as radiation monitoring and physical fitness tests. In addition, crew conferences with ground specialists can be coordinated.

Inflight oral hygiene includes toothbrushes and toothpaste with dental floss. For future long-term flights, the use of electric toothbrushes is recommended, as they remove dental plaque more effectively than manual tooth brushing [4]. Caries and gingivitis can be prevented by the timely reduction of plaque and thus oral bacteria. Besides kits for dental hygiene, on-board the International Space Station, medical equipment and instruments are available for a number of likely medical procedures. Set procedures with detailed instructions on how to use the available equipment for dental emergencies concern the following incidents [5]:

- Crown Replacement
- Total Avulsion / Complete Tooth Loss
- Exposed Pulp
- Injection Technique
- Temporary Filling
- Tooth Extraction
- Toothache

The procedure for 'Dental – Crown Replacement' (p. 525) notes that "*if there is no pain, especially when eating or drinking*" astronauts shall "*stow crown in secure location and crown can safely be placed upon return.*" Astronauts shall "*perform crown replacement procedure in event of pain and discomfort.*" As such, crown displacement on orbit is prevented if possible. In case of an emergency, pain can be suppressed until medical help back on Earth is available. In case of an extreme emergency, tools are available to extract the tooth.

3. Potential Dental Problems

We can assume that astronaut's dental health is checked prior to a long-term flight with even greater care than it is today. One might even think of not sending an astronaut with a dental filling or inlay and we can assume additional selection criteria for future astronauts related to the dental condition.

However, if we assume that the dental health of the astronauts is extraordinary and the astronaut is taking care of his oral health during the mission, there are still a number of threats that cannot be taken care of in advance.

3.1 Threats and Consequences

In general, the following three issues mainly threaten the tissues and structures of the stomatognathic system, including mandible, maxilla, temporomandibular joints, masticatory muscles and teeth:

1. Dental plaque
   This biofilm, rich in different bacterial species attaches to and grows on the tooth surfaces. If not removed it can promote caries, gingivitis and periodontitis.
2. Oral parafunction and other habits
   Dysfunctional activities of the teeth, mandible, cheeks, lips and tongue. This includes bruxism and habits like pen chewing and fingernail biting. Parafunctions accompanied by muscular hyperactivity and hypertonicity can be caused or increased by different psychological and physical stressors like toxic work environment and occlusal interferences. Extreme parafunctions can lead to muscle, temporomandibular joint and dental pain.
3. Acute Trauma
   Severe physical injury caused by an external source, such as an accident or impact, can cause bone and tooth fractures and other damages of hard and soft tissues.

On long-duration missions, dental plaque can be reduced or even prevented through strict oral hygiene. So it is more likely that trauma and stress induced bruxism will be main causes for dental problems and orofacial pain, rather than caries, gingivitis and periodontitis. Further the likelihood of acute trauma and thus dental accidents is increasing on long-term missions [6].

While plaque and bacteria (1) as a cause can almost be neglected, medical consequences related to parafunctions (2) and acute trauma (3) cannot. Potential consequences are the loss of crowns, fillings and tooth fractures.

On Earth, an occlusal appliance[1] can be used after trauma and/or stress induced bruxism (grinding and/or clenching of teeth) as mechanical bandage. It can be of help to stabilize the maximum occlusion and to reduce hyperactivity of the masticatory muscles. This can result

[1] An occlusal appliance or splint is a removable intraoral device to stabilize and optimize the dental occlusion or to eliminate contacts of the posterior teeth for reducing muscular hyperactivity.

in a reduction of myofascial [2] and/or temporomandibular[3] joint pain [7, 8]

For both cases, medical consequences related to parafunctions (2) and acute trauma (2) technical appliances can produce relief and remedy.

3.2 CAD-CAM-Technology

The technology of computer-aided design and computer- aided manufacturing (CAD-CAM) is becoming also increasingly important in the field of dentistry and dental technology. The basic principle of the procedure is as follows:

The teeth and if necessary the surrounding soft tissues are scanned in high resolution and three-dimensionally directly in the patient's mouth with a handheld intraoral scanner (Fig. 2). With the recorded data set the computer is generating a 3-D view of the scanned area that can be used for diagnostic purposes and treatment planning. The virtual model can also be transferred online to a dental-lab for designing the planned denture or other appliances. The data set of the virtual designed denture can then be used to manufacture the denture using printing, laser-melting or milling technology.

It should be noted that the CAD-CAM method will definitely play a key role in manufacturing objects like tools and spare parts during a long-duration mission.

The following section describes a case study of a dental injury following an accident with an acute traumatization of a lower premolar.

4. A Case Study of Dental Injury

This theoretical case study for the replacement of a dental restoration is based on the fictional accident of an astronaut during an interplanetary mission. During a routine work the astronaut tumbles, falls down and injures his jaw. (Fig. 1A).

Which teeth are traumatized depends on the direction of the impact. For example frontal teeth are most likely affected by acute injury of the midface Possible consequences include severe toothache, enamel, crown or root fracture, or even a dislocation or luxation of the tooth.

4.1 Clinical Situation and preliminary Diagnosis

The astronaut is in pain or with severe discomfort and / or dysfunction caused by an accident (Fig. 1B). After a preliminary visual inspection, either by the astronaut himself or by a colleague, a preliminary diagnosis is made. Possible indications could be that a filling, a partial crown or crown is lost or part of a tooth is broken. The astronaut determines what indication might be the case and immediately reports it to mission control on Earth. In case the astronaut has pain, pain-relieving medication is available.

Fig. 1A and 1B. The fictional astronaut has lost a crown and is now in severe tooth pain. He is disabled and needs medical aid. (Image credits: space-craft Architektur, Krljes)

4.2 Intraoral scanning Procedure and data transmission

Following a preliminary medical check and diagnosis by the astronaut himself or one of his crewmates, the intraoral scanning is prepared. Before the scan, a message is sent to Earth, in order to announce this incident and possible further actions to the mission control centre. The mouthpiece of the oral scanner is sterile packed; separate spares are available for each crewmember. The scan has to be conducted on a clean support, meaning that the oral area has to be cleared off potential obstacles.

[2] Pain associated with inflammation of muscle and/ or fascia surrounding the muscle.

[3] Pain associated with inflammation of the jaw joint.

Fig. 2. The astronaut (OEWF) scans his teeth and oral soft-tissues with an intra-oral scanner during the Amadee-15 mission. (image credit: H. Meusburger)

The intraoral scanning process (Fig. 2) takes only few minutes. Fig. 2 shows the astronaut conducting the scan by himself. In case, he is not feeling well, the procedure can be executed by a crewmate. Both procedures had been tested under laboratory conditions. It has been found that the more experienced the operator, the faster and accurate is the 3D scan. The high-resolution 3D-scan is stored and reviewed for completeness. After that the scan data is immediately transferred to Earth.

The current data rate direct-to-Earth varies from about 500 bits per second to 32,000 bits per second [9]. All space missions so far have relied on radio frequency communication. However, the demand for more data capacity increases and NASA has already proved that laser communication will extend its communication capabilities (cf. Lunar Laser Communication Demonstration). With future Laser Communication Technology, increased data resolution and much faster transmission can be achieved [10]. Table 1 shows a comparison of sending the 3D data file with RF and Laser Technology.

Download data rate direct-to-Earth comparison		
Technology	Rate	Transmission time for 30Mb file / 240 Mbit.
Radiowaves (Radio Frequency)	500 bits – 100 kbits/s	About 6,5 hours
Laser Communication	30 – 40 mbit/ s	About 6 min.

Table 1. Download date rate direct-to-Earth

Current comparable 3D data files are about 15 – 30 Mb in size. Thus, the data transmission of the 3D file takes about 6,5 hours with current technology. However, depending upon the scanned area, files can be up to 100 MB.

There is always the risk, that after approval on Earth, the scan cannot be used for 3D modelling, and would thus have to be repeated. In order not to lose time due to transmission failures, the authors propose to prepare up to 3 different scans and send them to Earth one after another.

4.3 Data Reception and Diagnosis

After transmission and reception of the 3D-data, the Earth-based dental surgeon verifies the file according to medical and technical aspects (Fig. 3):

- The file should be complete with no data voids.
- Data resolution shall be sufficient.

Based on the 3D-scan and considering additional information like dental imaging done before launch (Fig. 4A, 4B), audio files and written reports sent by the crew, the dental surgeon assesses the clinical situation and plans the treatment. In addition, the dental surgeon can refer to the medical data of the individual astronaut that has been conducted before the mission began.

Fig. 3. The dentist approves the data and hands it over to the dental technician. (image credit: space-craft Architektur, Krljes)

In this case, the impact has caused an extensive crown fracture of a lower premolar. Although the patient is suffering from severe tooth pain, the intraoral inspection shows that the pulp (tooth nerve) is not exposed.

(If the pulp is exposed a root canal treatment is indicated. If the root is fractured the tooth fragments have to be extracted. Both treatments are sensitive and delicate procedures that should only be executed by a well-trained person.)

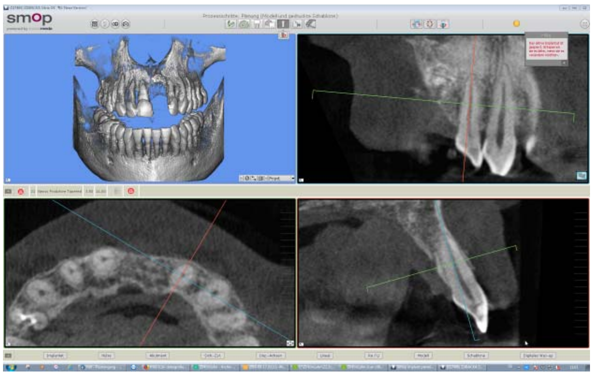

Fig. 4A. Example of cone beam computed tomography (CBCT). It shows the bone structure and morphology of the teeth, pulps and root canals.

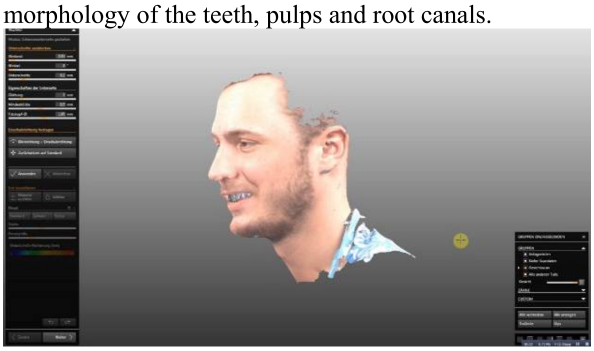

Fig. 4B. Example of a 3D scan of the whole skull and dental area, including different mimicries.

4.4 Design Procedure and Data Transmission

Following the treatment planning, the data is transferred to the dental technician for designing the partial or full crown (Fig. 5A) that shall cover and complete the fractured tooth. Additionally a positioning guide (Fig. 5B) is designed that will make sure that the partial crown will be placed correctly on the fractured tooth. Given a block anaesthesia for the injured and painful mandible is necessary, an injection guide (Fig. 5C) for placing the injection needle correctly can also be designed.

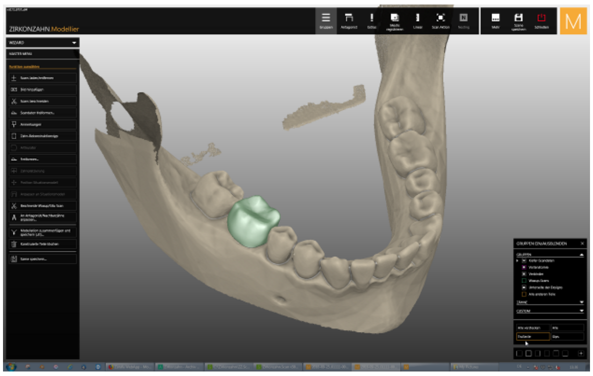

Fig. 5A. Image of a virtual crown.

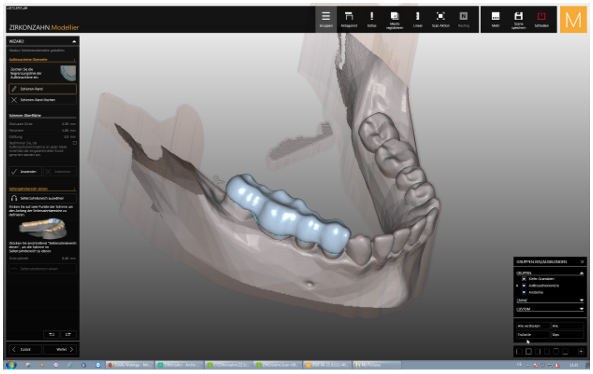

Fig 5B. Image of the virtual positioning guide.

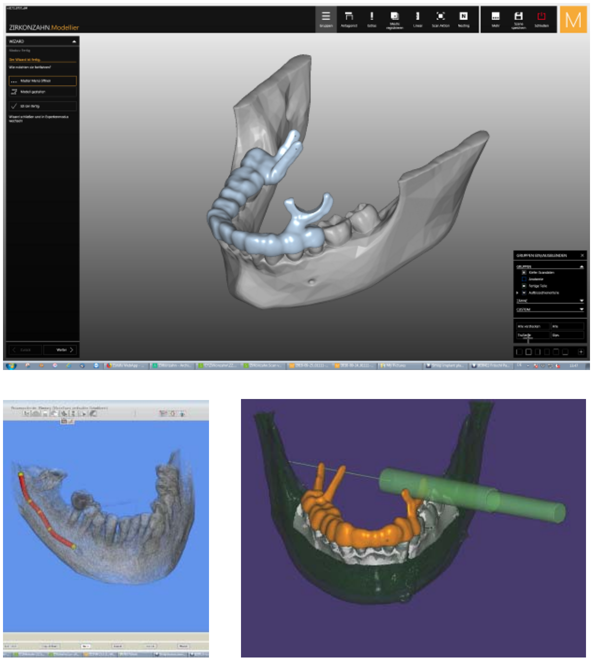

Fig 5C. Using the CBCT data of the patient's mandible and the intraoral scan of his lower teeth allows the virtual design of an injection guide.

Following the virtual design process, the final products are virtually and physically validated on Earth.

For the physical test, the whole printing process is simulated in the laboratory. After printing, the test objects are examined for potential imperfections. (Fig. 7A-C)

After successful certification, the 3D data files are transmitted to Mars. The file format for the data set is a file format native to stereolithography CAD (STL) software. The size of a crown is about 2,5 MB, the size of the positioning guide about 3 MB and the size of the injection guide is about 10 MB.

4.5 3D Fabrication Process

On the interplanetary base, a 3D-printer is used to manufacture the crown, the positioning guide and if necessary the injection guide. (Fig. 5 A-C)

Fig. 6. The virtual crown is printed with a 3D printer. (Image credit: space-craft Architektur, Krljes)

The whole process has been simulated repeatedly under laboratory conditions (Fig. 8-10). For the simulation of the procedure, an intraoral scanner (GC AADVA IOS™), a computer station, and a dental kit was used. The materials used for the simulation are standard state of the art materials used in dentistry.

The crown is made from Methacrylat Oligomere material. Those are high quality, light curing adhesive synthetics and represent state of the art technology. For future space flight applications, it is most likely that materials to be used will be produced in-situ. This issue will need further attention.

The positioning guide and the injection guide are made of Polymethylmetacrylate (PMMA). The material is commonly used in dentistry due to its biocompatibility. It is used for all dental prosthetics, artificial teeth, and orthodontic appliances.

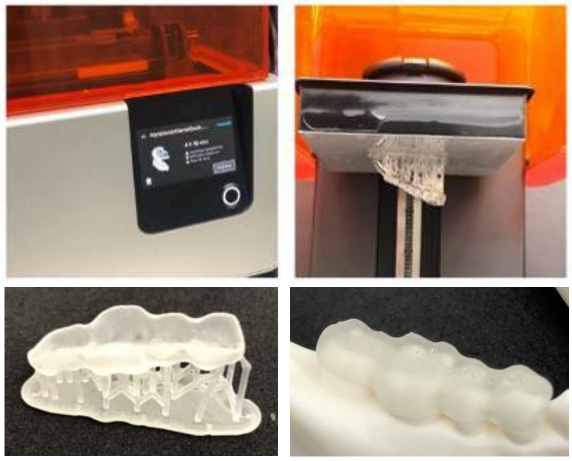

Fig. 7 A-D. Sequence of printing process

A: The 3D printer calculates the time and consumption of material based on the received file.

B: The UV protective cover of the printer is opened. The file has been printed.

C: The printing result immediately after printing.

D: The result following manual post-processing.

Following a theoretical (virtual) and practical (printed) simulation under normal laboratory conditions, the proposed procedure has been partly simulated during a Mars simulation mission of the Austrian Space Forum in August 2015 [11]. The results were presented in the previous paper [1]. During the simulation it became evident, that the inclusion of a positioning guide would greatly improve the process. As a result, the procedure was adapted accordingly and a position guide was integrated. Several kinds of injections guides were developed and tested. Fig. 10 A shows an injection guide for a disposable syringe.

4.6 Insertion of the Restoration & Controlling

A trained crewmember inserts the crown (Fig. 8A) by using adhesive techniques. The positioning splint (Fig 9A) helps to place the crown in the correct position. In case of pain, the injection guide (Fig. 10A) is connected to the on-board medical system with an automatic syringe.

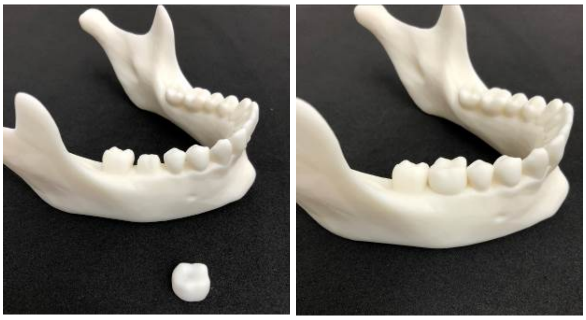

Fig. 8A and B. Printed crown.

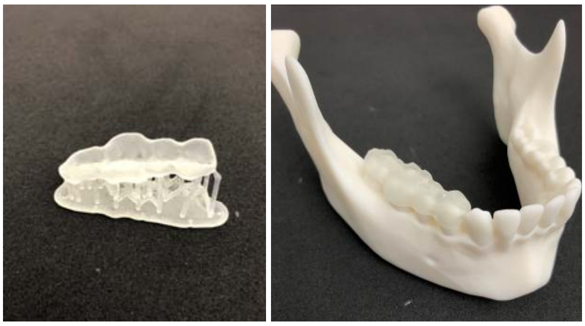

Fig. 9B and C. Printed positioning splint.

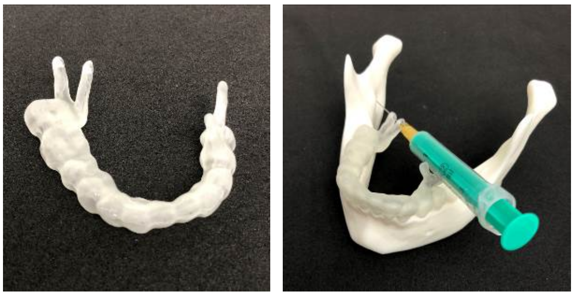

Fig. 10A and B. Printed injection guide. It can be used for connection to the on-board automatic syringe medical system.

If necessary the crewmember removes surplus cement (Fig. 11) and occlusal interferences.

Fig. 11. Test person controls the inserted crown by himself using a mirror during the Amadee Mars simulation mission. (image credit: P. Santek, OEWF)

5. Conclusion and Outlook

Long-term missions to the Moon, Mars and beyond require both specific equipment and astronauts with basic theoretical and practical knowledge to deal with dental and/or jaw problems.

The technology, infrastructure and materials used described in the paper reflect the state of the art and will change rapidly in the near future. Independently of technological advancements, great attention shall be given to the procedure and possible interfaces between the technology and human beings.

Besides the direct physiological impact on the human body, a change in gravity affects a wide range of human activities, like body movement, posture and locomotion and provides a dramatic challenge to human physiology [cf. 3]. Selected sequences of the treatment need to be tested in micro gravity to ensure a smooth working flow. A routine oral examination may be done without the aid of restraints. But as soon as forces are applied (eg. by pressing or pushing), restraints will be needed to support the astronaut. There are multiple kinds of restraints already available on orbit. Those possibilities and the needed type of restraint for the selected sequences need to be further explored.

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References

[1] S. Häuplik-Meusburger, U. Lotzmann, H. Meusburger, 2016, Dental Treatment during a human Mars Mission with remote support and advanced technology"; 46th International Conference on Environmental Systems (ICES 2016), Vienna; 10.07.2016 - 14.07.2016; in: "Proceedings International Conference on Environmental Systems".

[2] Hodapp Michael H. 2008. **Dental Concerns** in "Principles of Clinical Medicine for Space Flight" (ed. Michael R. Barratt and Sam L. Pool), Springer, New York

[3] Clément, Gilles. 2011. **The musculoskeletal system in space** (book chapter) in fundamentals of space medicine, volume 23 of the series space technologies library, 181–216. Springer.

[4] Yaacob M, Worthington HV, Deacon SA, Deery C, Walmsley AD, Robinson PG, Glenny AM. Powered versus manual toothbrushing for oral health. Cochrane Database of Systematic Reviews 2014, Issue

6. Art. No.: CD002281. DOI: 10.1002/14651858.CD002281.pub3.

[5] NASA [Medical Checklist] 2001. **International Space Station Integrated Medical Group (IMG) Medical Checklist**, ISS – All Expeditions. Mission Operations Directorate, 12 November 2001, NASA, Lyndon B. Johnson Space Center, Houston, Texas, JSC-48522-E4

[6] NASA [Dental Emergencies]. 2012. **Review of Spaceflight Dental Emergencies**. Anil Menon, The Unicersity of Texas Medical Branch, NASA Johnson Space Center Bioastronautics Contract, NASA/TM-2012-217368

[7] Lotzmann U. 1983. Okklusionsschienen und andere Aufbißbehelfe, Neuer Merkur, München

[8] Bumann A., Lotzmann U. 2002. TMJ Disorders and Orofacial Pain. The Role of Dentistry in a Multidisciplinary Diagnostic Approach, Thieme, Stuttgart

[9] NASA [Data Rates / Returns], https://mars.nasa.gov/msl/mission/communicationwithearth/data/. Accessed: Sep 2018

[10] NASA, NASA Laser Communication System Sets Record with Data Transmissions to and from Moon, October 22 2013, https://www.nasa.gov/press/2013/october/nasa-laser-communication-system-sets-record-with-data-transmissions-to-and-from/#.W6IPqvZCTcs, accessed: Sep 2018

[11] G. Grömer, A. Soucek, N. Frischauf, W. Stumptner, C. Ragonig, S. Sams, T. Bartenstein, S. Häuplik-Meusburger, P. Petrova, S. Evetts, C. Sivenesan et al., 2014, The Mars2014 Analog Mission; Astrobiology , 14, 5; p. 360 - 376.