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The role of smart medical systems in the Space Station

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Abstract

NASA is developing a Health Maintenance Facility to provide medical equipment and supplies requisite for the Space Station to be launched in the late 1990s. An essential component of this medical facility is a computerized Medical Decision Support System which will expedite medical officers' efforts to maintain the crew's health. The computerized system includes four major functions:

1. A data collection and storage system with a self-contained medical expert scheme for performing treatment protocols. The expert system has 'data driven' and 'time driven' capabilities to facilitate automatic decision-making functions.
2. An integrated medical record and medical 'reference' information management component.
3. An inventory management system for medical supplies and pharmaceuticals.
4. Video, audio, and data communications between the medical officer in the Space Station and ground-based medical personnel.

This paper discusses the design of such computerized data collection, communications and expert medical systems as will be developed for use in a Space Station Health Maintenance Facility.

Introduction

Historically the United States has assigned minimal priority to 'complex' medical care in space, largely because most space flights have been of short duration and have maintained space vehicles in which astronauts could return to earth in event of a medical emergency. The Space Station currently being designed presents new challenges [1–5]. The design calls for crew to be transported by shuttle, but to then remain isolated in the Space Station for 45 to 180 days, a much longer period of time than most previous flights. The shuttle can be in space for approximately 7 days; it was designed to be a 'space truck' and cannot carry large supplies of fuel, rations, and oxygen for longer flights. For the first time in the space program, an 'ambulance' may not be called to return sick or injured crew members. Such a call, were it even feasible, would be very expensive (about $300 million) and slow (14 to 45 days). As a result, the Space Station must be equipped with a self-sufficient medical unit and to this end, NASA engineers are designing a computerized Health Maintenance Facility [1–5].

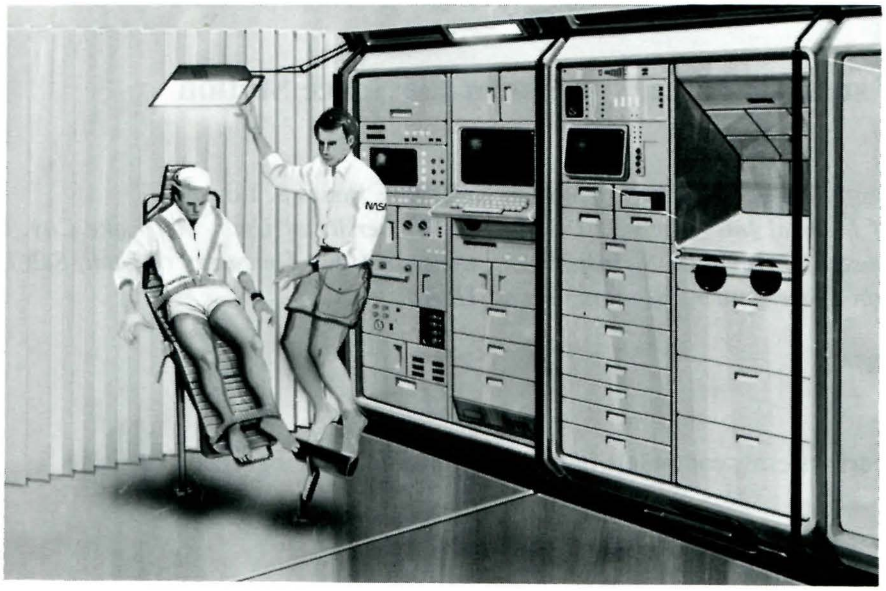

Fig. 1. Conceptual drawing of the Space Station Health Maintenace Facility with a patient in a 'restraint' – the microgravity analog of a bed. See text for description of the equipment modules.

Space Station Health Maintenance Facility

There are 8 design guidelines for the Space Station Health Maintenance Facility (HMF) [5]:

1. Capacity to accommodate a single critical care patient, or 4 to 6 patients with minor injury or illness, for 45 days.
2. Capacity for two medical officers with expertise comparable to that of paramedics or emergency medical technicians.
3. Equipment and supplies approximately 3 m^3 and 950 Kg.
4. Ability to perform minor emergency medical and surgical procedures.
5. Ability to communicate with NASA flight surgeons at medical support centers on earth.
6. Protocols to prioritize medical procedures and algorithms for specific methodologies.
7. Commercial technologies that are functional in the Space Station's microgravity environment.
8. Medical instruments which automatically communicate data to the HMF computer through a Medical Information Bus.

An artist's conceptual layout of the Space Station Health Maintenance Facility is shown in Fig. 1. The patient is held in a restraint and is surrounded by support equipment. The bank of equipment behind the medical officer (standing) contains: a dental instrument module, a pulse oximeter, a ventilator, suction and air fluid separator, IV pumps, a patient monitor, and defibrillator. The second bank (with the large screen) includes an Intra Venous (IV) fluid production and support system, a computer terminal and medical information system. The third bank contains an X-Ray and imaging system [4] and medical supplies storage space. The fourth bank (right side of the photo) includes a microbiology workstation, clinical laboratory system, and pharmacy module.

Figure 2 shows the major support modalities of the Space Station Health Maintenance Facility: prevention, diagnosis, and therapy [5]. Crucial to the operation of the HMF is the computerized medical decision support system which integrates data from all three care support modalities (center of the diagram).

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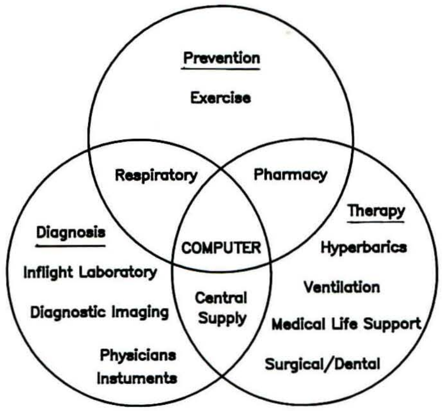

Fig. 2. Combining the capabilities of the Space Station showing the computer system at the center of prevention, diagnosis, and therapy.

tioning in microgravity. Diagnostic capabilities will include clinical laboratory facilities such as chemistry, hematology, and microbiology, as well as radiographic imaging. Medical care in the Space Station will include physiological monitoring, cardiac defibrillation, IV fluid support, pharmacy, capabilities for minor surgery, and a support ventilator.

Which medical problems to expect

The Health Maintenance Facility will function as physician's office, pharmacy, hospital, clinical laboratory, and exercise station. Instrumentation and computer facilities will utilize ground-based technology. To determine the requirements of such a facility, a careful estimation of potential medical problems was needed. Extensive studies have been made of the physiological changes associated with microgravity, but only limited data existed for inflight disease and injury incidence. There was well-documented medical information concerning Antarctic crews, nuclear submarine crews, and US military populations, but these comparable populations were imperfect models and the data required extrapolation to be useful.

Using anonymous computerized hospital records for calendar year 1985, a study was made of more than 1.2 million US Army and Navy personnel. The records contained the International Classification of Diseases 9th Edition Clinical Modification (ICD–9–CM) categories, length of illness, mortality, and disability retirement information [6, 7]. These data were adapted to the Space Station environment by taking the following facts into consideration: 1) that microgravity would reduce traumatic injuries; 2) that crew members would be placed in isolation several days before the mission, and therefore only microorganisms brought on board would colonize; 3) that there would be cardiopulmonary and musculoskeletal deconditioning as well as bone demineralization; 4) that stricter selection criteria would be applied to the Space Station crew than had been operative with military personnel.

A 'Medical Impact Score' was used to rank the diseases and injuries by incidence rate and consequence to the crew. Results of this analysis are shown in Table 1 [6, 7]. The fact that cardiac dysrhythmias and acute myocardial infarction rank at the top of the categories clearly indicates a need for monitoring capabilities similar to those in a coronary care unit. Note also that joint and bone dis-

Table 1. Top 15 categories of medical problems expected on Space Station.

Rank	ICD-9 Code	Category
1	427	Cardiac dysrhythmias
2	410	Acute myocardial infarction
3	780	General symptoms
4	724	Disorders of back, other & unspecified
5	717	Internal derangement of knee
6	733	Disorders of bone and cartilage, other
7	718	Derangements of joint, other
8	722	Intervertebral disc disorders
9	296	Affective psychoses
10	135	Sarcoidosis
11	695	Erythematous conditions
12	719	Disorders of joint, other & unspecified
13	070	Viral hepatitis
14	592	Carculus of kidney and ureter
15	728	Disorders of muscle, ligament, and fascia

Based on evaluation of hospitalization records for the US Army and Navy (1.2 million population) for the year 1985 [6, 7].

orders have projected frequent occurrence which clearly suggests a need for an X-Ray imaging system on board the Space Station.

Design requirements of medical decision support system

The Health Maintenance Facility Medical Decision Support System must meet the following requirements [5]:

1. Provide an on-board integrated computerized medical record. Since conventional paper medical records are heavy and cannot be easily shared with ground-based flight surgeons and consultants, the medical records will be computerized.
2. Provide preventive, diagnostic and therapeutic management algorithms. In case communications with ground based medical experts is unavailable, computerized diagnostic and treatment protocols will be self contained in the support system.
3. Provide electronically retrievable NASA contingency checklists and procedures and indexed medical references. References such as the Physicians Desk Reference (PDR) will be available in electronic form.
4. Transmit measurement data, images, medical monitoring alarms, and charted information to ground-based flight surgeons and medical consultants as necessary.
5. Provide two-way air-to-ground 'private' and 'public' electronic mail and voice communications. The 'private' medical conference is essential for confidentiality among crews and ground staff and family.
6. Provide computer-assisted inventory management of medical supplies and pharmaceuticals, since the Space Station will be in continuous use and will continually need to be resupplied.

In addition to these requirements, the Space Station has several other constraints:

a) All physiological and laboratory data will be processed by 'smart' monitors on board the Space Station.
b) Medical storage space will be limited.
c) Only clinically validated medical methodologies will be practiced.
d) All systems software must be written in the Ada computer language.
e) Computer processing support must be based on software and hardware components common to the remainder of the Space Station Data Management System.

Hardware design

The Space Station represents a major technological advance in computing capability, compared with that in former manned space flight. The network supporting the Space Station, of which the Medical Decision Support System is one node, will consist of distributed 4 million instruction per second computers, known as Standard Data Processors, connected via a 100 million bit per second fiber optic network. Both fixed and portable workstations will be supported from a global network and mass storage system. Each component in the network will have a redundant backup and will provide reliable service to all Space Station systems including the HMF.

Medical Information Bus (MIB)

Technology in Intensive Care Unit (ICU) patient monitoring is just beginning to address the problem of how to centrally collect data from a wide variety of bedside instruments [9, 10]. A Medical Information Bus (MIB) has been designed to allow different medical instruments, from different manufacturers, to communicate with a host computer over a common communications link [9]. Proposed standards for the MIB are being developed by the Institute of Electrical and Electronic Engineers (IEEE) and designated P1073. The existence of an MIB standard will allow manufacturers to integrate standardized hardware and software into their monitoring devices. LDS Hospital has begun to integrate prototype MIB hardware and software into a wide variety of medical devices. Clinical experience with the MIB on IVAC 960 IV pumps in the Thoracic Intensive Care Unit has provided insight into problems associated with the application of this communications strategy. For example, an IV pump can report changes in infused volume every 0.1 ml, but clinicians do not require that level of detail; recording such information is like adding 'noise' rather than 'signal' to the record. It was therefore necessary to develop methods of recording only relevant information in the clinical record.

Further hardware and software interfaces now undergoing clinical testing include: the Ohmeda 370 Pulse Oximeter, the Siemens 900C Ventilator, the Dinamap Vital Signs Monitor (Models 1846 and 8100), the Puritan-Bennett 7200A Ventilator, the Spacelabs 90600A Series Monitors, the Oximetrix 3 SO_2/CO monitor and several blood gas instruments.

Clinical experience has revealed important strategies regarding use of the MIB: 1) Better methods to identify mechanical or electrical disturbances must be designed and validated, so that medical devices will transmit only 'representative' information. 2) MIB systems must be able to collect information at several levels; for example, at certain times it may be appropriate to measure 0.1 ml volume changes from an IV pump, while at other times 10 ml changes would be sufficient. 3) The host computer must be capable of presenting meaningful information from the MIB.

The MIB has proven valuable for reporting, record keeping, and decision making at LDS Hospital. Detailed charting during crisis situations, almost impossible with manual methods, is now convenient and accurate. Furthermore, with the MIB it is possible to integrate data from diverse instruments and laboratories. Such data integration is crucial for medical decision making, for the provision of information to medical officers in the Space Station, and for communication to flight surgeons and consultants on earth.

NASA actively supports the IEEE MIB committee and is committed to interface its instruments to the host computer on board the Space Station.

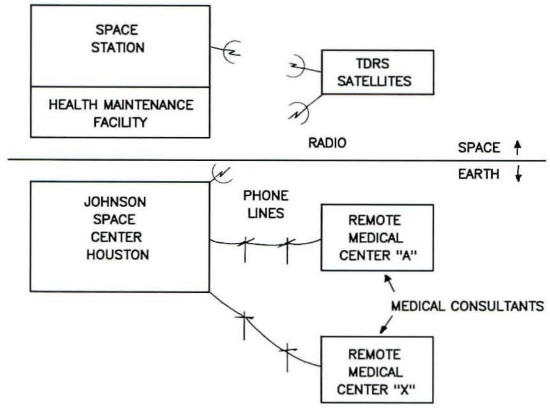

Fig. 3. Block Diagram of the Communications Network of the Space Station Decision Support System with the linkage to computers and flight-surgeons at Johnson Space Center in Houston, Texas. TDRS = Telecommunications and Data Relay Satellites.

Communications systems

The Space Station crew will be in constant contact with earth via a complex communication system which will link four Telecommunications and Data Relay Satellites (TDRS), all in high geosynchronous orbit. Since the Space Station will be in low earth orbit (the same orbital path as the shuttle), communications will be made to earth via the TDRS communications system. This will avoid the current problem on shuttle flights where segments of the orbit have no radio contact with earth stations.

The Space Station communications system will have video, voice, and data transmission. These two-way air-to-ground links can be 'public' (i.e., new conferences) or 'private' (i.e., conversations and pictures transmitted to flight surgeons and family members).

The Medical Decision Support System will have both 'down-link' and 'up-link' communications with NASA control on earth. To supplement the on-board decision support, ground based medical experts will be on-line consultants. Figure 3 shows the conceptual design of the ground network for the Health Maintenance Facility. The ground consultants will have workstations with video, radiographic imaging, audio, and data review capabilities. Thus, if NASA ground-based flight surgeons at Johnson Space Center need other medical expertise, such as from remote medical centers or clinics, the ground-based consultants will be able to quickly access the flight crew's medical data through the communications capability of the Health Maintenance Facility.

Decision support system

Shortliffe has defined a Medical Decision Support System as 'any computer program designed to help health professionals make clinical decisions' [11]. He also notes that *any* computer system that deals with clinical data or medical knowledge is intended to provide decision support. For example each of the following programs can be considered a medical decision support system: 1) information retrieval, such as MEDLINE bibliographic searches; 2) focus of attention, such as drug alerts; and 3) patient-specific consultation, such as algorithms.

The Space Station Medical Decision Support System is similar to the HELP system operational at LDS Hospital [12–17]. Pryor and colleagues have programmed the HELP system to provide the following types of decision support [12–17]:

1. Alerting – Automatic notification of 'time-critical' or action-oriented events; for example, notification of abnormal laboratory values, vital sign trends, or medication contraindications.
2. Interpreting – Assimilation of data resulting in a conceptual understanding; for example, ECG interpretation for both morphology and rhythm, or interpretation of blood gas data.
3. Assisting – Use of decision support to speed or simplify some action; for example, assistance with clinical orders, or data collection during a history or physical exam.
4. Critiquing – Analysis and validation of decisions [18]; for example, critiquing drug prescriptions.
5. Diagnosing – Application of a medical 'model' for the purpose of understanding the state of a physiological system; for example, diagnosing using a Bayesian strategy.
6. Managing – Algorithms for clinical treatment; for example, suggestions about ventilator management.

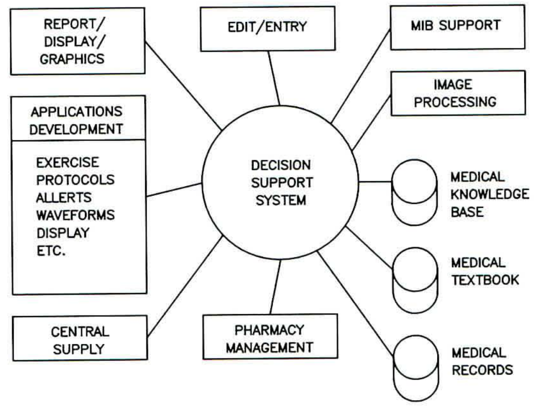

Fig. 4. Block diagram of the computerized Medical Decision Support System showing its interconnection to data gathering equipment, knowledge bases and reporting functions.

Figure 4 is a block diagram of the Medical Decision Support System. The Space Station system will have 4 major areas: 1) the medical record, 2) a medical knowledge base, 3) a medical textbook/ checklist database, and 4) an inventory maintenance database.

The medical records and knowledge-base areas will simulate features of the HELP system [12–17]. Currently, many computerized medical decision support systems are passive, i.e., they require the physician or health care provider to recognize a need for the system and enter the data by hand. Conversely, the HELP system is active, i.e. medical decisions are automatically generated, based on patient-specific data contained in the data base, without data entry by the physician. A similar design will be used on the Space Station, including using the MIB.

Shortliffe maintains that decision-support programs operate at optimum effectiveness when they are integrated with routine data management functions [19, 20]. The HELP system has these capabilities since it integrates data from a wide variety of sources and can be both data and time driven [12–17]. A data-driven medical decision support system provides a tireless watch over the patients. It culls an enormous volume of low-yield clinical data to discover the occasional mistake if one occurs. Data-driven systems can produce virtually errorless medicine by scrutinizing data and considering every possible inference – something human practitioners cannot achieve [21]. To realize this advantage, a decision-making system must be integrated into a comprehensive clinical database. Secondly, the execution of the decision logic must be an automatic consequence of data capture or the passage of time (i.e., time driven), and not be dependent on the health care provider's conscious activation [11, 21].

Discussion

When the Space Station is launched and assembled in the 1990s, medical computer technology will be sophisticated enough to evaluate the Medical Decision Support System, and the requisite electronic medical record. McDonald and associated ascertain that over the next few years, on-line medical records will become technically and economically feasible [22]. Such technology will have three major advantages:

1. Improved logistics and organization of the medical record, to speed treatment and improve efficiency.
2. Automatic computer review of the medical record, to limit errors and control cost.
3. Systematic analysis of past clinical experience, to help guide future practice.

The methods of data collection and decision-making presented in this paper are clinically operational or have been tested in a prototype form. The space program nurtured micro-computer technology so prevalent in modern sophisticated bedside monitors. Now, it is likely that the space station inhabitants will benefit from the medical computerized data collection and decision support systems developed with the aid of micro-computers.

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