Planetary and Space Science 58 (2010) 717–723

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

The use of the National Research Council of Canada's Falcon 20 research aircraft as a terrestrial analogue space environment (TASE) for space surgery research: Challenges and suggested solutions ☆

A.W. Kirkpatrick [a,b,c,*], M.A. Keaney [d,e], K. Bentz [f], M. Groleau [e], M. Tyssen [e], J. Keyte [e], C.G. Ball [a], M.R. Campbell [g], S.M. Grenon [h], P. McBeth [a], T.J. Broderick [i]

[a] Departments of Surgery, Foothills Medical Centre, Calgary, Alberta, Canada
[b] Critical Care Medicine, Foothills Medical Centre, Calgary, Alberta, Canada
[c] Regional Trauma Services, Foothills Medical Centre, Calgary, Alberta, Canada
[d] Departments of Pathology and Laboratory Medicine, University of Ottawa, Ottawa, Ontario, Canada
[e] Animal Care and Veterinary Service, University of Ottawa, Ottawa, Ontario, Canada
[f] Karl Storz Endoscopy, Mississauga, Ontario, Canada
[g] Paris Regional Medical Center, Paris, TX, USA
[h] University of British Columbia, Vancouver, British Columbia, Canada
[i] University of Cincinnati, Cincinnati, OH, USA

ARTICLE INFO

Article history:
Received 28 January 2009
Received in revised form
22 May 2009
Accepted 2 June 2009
Available online 9 June 2009

Keywords:
Space analogue environment
Surgery
Parabolic flight
Space flight
Critical care medicine

ABSTRACT

Emergency surgery will be needed to prevent death if humans are used to explore beyond low earth's orbit. Laparoscopic surgery (LS) is envisioned as a less invasive option for space, but will induce further stresses and complicate logistical requirements. Thus, further study into the technology and physiology of LS in weightlessness is required. We recently utilized the National Research Council of Canada's Flight Research Laboratory's Falcon 20 aircraft as a terrestrial analogue space environment (TASE) for space surgery research. The Falcon 20 had never been used for this purpose nor had the involved teams collaborated previously. There were many process challenges including the lack of antecedent surgical studies on this aircraft, a requirement for multiple disciplines who were unfamiliar and geographically distant from each other, flight performance limitations with the Falcon 20, complex animal care requirements, requirements for prototypical in-flight life-support surgical suites, financial limitations, and a need to use non-flight hardened technologies. Stepwise suggested solutions to these challenges are outlined as guidelines for future investigators intending similar research. Overall, the Falcon 20 TASE, backed by the flight resources, especially the design and fabrication capabilities of the NRC-FRL, provide investigators with a versatile and responsive opportunity to pursue research into advanced medical techniques that will be needed to save lives during space exploration.

1. Introduction

Planning is now underway for extended human exploration beyond low earth orbit (Ball and Evans, 2001). Many unresolved technical and physiological questions remain. These include, but are not limited to how to ensure crew health, as well as how to provide for emergency surgical treatments (Kirkpatrick et al., 1997, 2001, 2005a,b; Campbell, 2002; Dawson, 2008; Silverman and McCartney, 2008). To this end, the authors recently conducted the first large animal surgical research in a parabolic flight terrestrial analogue space environment (TASE) performed in Canada in conjunction with the National Research Council of Canada's Flight Research Laboratory (NRC-FRL). This work required the collaborative efforts of a multidisciplinary team from academic, government, military, and commercial backgrounds. These groups had never worked together in a project that was constrained by time and finances. The purpose of this report is to describe the challenges and suggest potential solutions to guide future researchers in planning similar experiments.

☆This project was funded by the Canadian Space Agency through Contract 08/7004098 and supported in part by an unrestricted educational grant from the Urodynamix Corporation, Vancouver, British Columbia. This material was presented in part at the Canadian Aeronautics and Space Institute ASTRO 2008 Meeting, Montreal, Quebec, 2008.

* Corresponding author at: Medical Director, Regional Trauma Services, Foothills Medical Centre, 1403 29 Street NW, Calgary, Alberta, Canada T2N 2T9.
Tel.: +1 403 944 2888; fax: +1 403 944 8799.
E-mail address: andrew.kirkpatrick@calgaryhealthregion.ca (A.W. Kirkpatrick).

0032-0633/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pss.2009.06.002

2. Background

Laparoscopic surgery (LS) is a surgical technique involving the use of miniaturized television cameras to permit complex operative procedures inside the peritoneal cavity, thus reducing the inherent surgical trauma. To perform LS however, gas is insufflated under pressure into the peritoneal cavity to create the physical volume to allow one to operate (known as the "domain"). The human body undergoes a profound physiologic reconditioning to accommodate to weightlessness when residing in space for a prolonged period of time. Changes such as reduced blood volumes, cardiac deconditioning, alterations in vascular tone and neuroendocrine function, loss of the protective bony skeleton, and possible immune suppression are all relevant (Meehan et al., 1992; Huntoon et al., 1993; Kirkpatrick et al., 1997, 2001). It is pertinent that the ill and injured human is also markedly susceptible to adverse effects of raised intra-abdominal pressure, which may have adverse effects throughout the body but are particularly notable as impaired respiratory, cardiac, and renal function (Malbrain et al., 2005, 2006; Kirkpatrick et al., 2006). It was predicted that the adverse effects of raised IAP in any critical illness would be exacerbated further by the physiologic changes expected after prolonged weightlessness (Kirkpatrick et al., 2005a,b).

LS can be conducted without pressurized gas in the abdominal cavity using a simpler procedure known as gasless laparoscopy (GLS). In this technique, GLS is performed by employing various lifting devices to elevate the abdominal wall. It has not become widely adopted, however, due to concerns regarding inadequate domain. We (Campbell et al., 1996, 2001) have previously observed that in weightlessness the porcine abdominal wall seemed to spontaneously elevate upon entering microgravity. Hoping that these spontaneous abdominal wall changes might assist with GLS, we examined our ability to conduct GLS in weightlessness (Kirkpatrick et al., in press), as well as evaluate its physiologic consequences (Kirkpatrick et al., 2009). Conducting these investigations required a suitable research laboratory that would allow the controlled manipulation of gravity. Thus, developing the systems, equipment, protocols, and professional relationships to permit the use of the Falcon 20 as a TASE constituted a critical project requirement, and serves as the substance of this report.

3. The value of surgical studies using parabolic flight as a TASE

To date, no human surgical procedure has ever been required or performed in spaceflight, although surgery on mice with full recovery was performed during the Neurolab STS-90 mission (Campbell et al., 2005). Parabolic flight TASE's have thus been invaluable to study critical principles and to understand the enabling requirements for surgical procedures in weightlessness while remaining on earth. A number of previous studies have utilized various TASE's in larger aircraft, such as the KC-135 previously flown by NASA's reduced Gravity Program, or the Airbus A300 flown by the European Space Agency. These studies have examined procedures ranging from simple to quite complex intra-abdominal and intra-thoracic procedures on animals (Campbell and Billica, 1992; Campbell et al., 1993, 2002; Pinsolle et al., 2005), and Martin et al. (2008) even performed minor surgery on a human volunteer. All studies in such environments must be "parceled" in stepwise fashion into brief windows of weightlessness. It has been consistently found that surgical procedures can be performed with no more difficulty in weightlessness than in normal 1 g, if the principle of restraint of the patient, operating personal and surgical hardware is adhered to Campbell and Billica (1992); Campbell et al. 1993 (2002); Campbell (2002); Pinsolle et al. (2005); Martin et al. (2008). Practically, however, these TASE platforms are much larger aircraft with mature dedicated programs to encourage surgical research in parabolic flight compared to the NRC-FRL Falcon 20.

4. Preparation of a Canadian Parabolic Flight TASE Surgical Research Laboratory

The Canadian Space Agency (CSA) and the National Research Council of Canada Flight Research Laboratory (NRC-FRL) jointly collaborate to support experiments requiring brief periods of weightlessness in parabolic flight. The NRC-FRL maintains and operates a small fleet of dedicated research aircraft to support research projects in-flight mechanics, avionics and airborne research experimentation. The NRC-FRL has developed two aircraft as TASE research platforms, a T-33 and a Falcon 20 that offer different capabilities and performance. The Falcon 20 aircraft is a twin-engine business jet with an on-board laboratory area of 5 m by 1.5 by 1.5 m, and capable of providing up to 23 s of effective weightlessness (Fig. 1). These periods of weightlessness are produced by a parabolic flight, where, the ballistic profile effectively renders an object or subject effectively weightless in a state more specifically denoted as microgravity (Nicogossian and Robbins, 1993).

To humanely and ethically perform surgical and physiologic studies in such a laboratory required the fabrication of a compact critical care/surgical suite on-board the Falcon 20. This suite was designed to provide critical care physiologic monitoring, full intravenous anesthesia, mechanical ventilation, laparoscopic surgery, and redundant digital video disc (DVD) recording capabilities. Time and gravity (gz) information from the Falcon 20 avionics system was digitally encoded onto the DVD recording systems. Relative lung compliance during varying intra-abdominal conditions and gravitational status was evaluated using a pressure-controlled ventilatory mode on the transport ventilator. Pre-flight ground labs involved evaluating surgical instrumentation, administration of general anesthetic, and providing extensive and continuous physiologic critical care support and monitoring to Yorkshire pigs which were physically transported from the University of Ottawa (U of O) Vivarium to the NRC-FRL. All intended in-flight procedures and measurements were first conducted on the ground in 1 g, while on-board the critical care/surgical suite during these rehearsals. Only after the investigators had studied and rehearsed all procedures in both the vivarium and on-board the Falcon 20 in the hangar in 1 g, and perceived that they would be feasible in flight, was the decision to proceed with the actual parabolic flights concluded. Thereafter, four consecutive days of surgery were studied during parabolic flights flown in March 2007.

5. Challenges related to conducting large animal surgical research in a Canadian Parabolic Flight TASE Surgical Laboratory

The challenges initiating this study included but were not limited to:

(1) No antecedent surgical studies on the Falcon 20 platform.
(2) Multiple skill sets and disciplines required but unfamiliar and geographically distant to each other.
(3) Falcon 20 aircraft flight performance limitations.
(4) Complex animal care requirements.
(5) No prototypical in-flight surgical life-support suites.