J R Army Med Corps 2002; **148:** 248-254

Aeromedical Evacuation Following Abdominal Surgery

W Sapsford

Introduction

It is generally accepted that there are no absolute contraindications to the movement of patients by air (1, 2). However, there are special physical and physiological factors that must be considered before subjecting a patient to the potentially hostile flight environment. The major considerations are altitude and airframe whilst minor considerations include space, noise, vibration, turbulence, G forces, temperature, humidity, fatigue, anxiety, time zone changes and airsickness.

The purpose of this review is to consider when, following abdominal surgery, a patient can be considered for aeromedical evacuation. This review will consider only fixed wing aeromedical evacuation (AE) in pressurised aircraft capable of maintaining a cabin altitude of 8000 feet or better, which depends primarily on the airframe and secondarily on the altitude flown but includes all fixed wing aircraft deployed on aeromedical evacuation missions in the RAF. Furthermore, this review will concentrate on patients following abdominal surgery.

Each aeromedical evacuation must be judged on its merits and in each case the anticipated benefits must outweigh the associated risks. In order to achieve this, the destination medical facility should be of a higher standard of medical care than the originating facility and the standard of care during aeromedical transfer should be at least equal to that of the originating facility.

The Problem

Altitude is the major consideration when considering AE of any patient in a fixed wing, pressurised aircraft. Cabin altitudes can be set on the flight deck but are limited by the flight altitude. Normal cabin altitude is set at 6000 feet for civilian flights at cruising altitudes but may be increased to 8000 feet in some airframes (mainly for economic reasons). In RAF operations in the C130 Hercules cabin altitude will vary between 3000 and 6000 feet at normal cruising flight levels of 22,000 to 26,000 feet, and in the VC-10 cruising at 30-35,000 feet the cabin altitude will be 6000 feet. The cabin altitude is unlikely ever to exceed 8000 feet during normal operations. This affects the partial pressure of oxygen in the inspired air and the volume of any non-equalised gases.

Boyle's law states that the volume of a gas at a constant temperature varies with the inverse of the pressure. At a cabin altitude of 8000 feet (2438 metres) above sea level the volume of a trapped gas will expand by 25-30%. This will affect all trapped physiological air within any gas filled organ in the body such as the lungs, sinuses and gastrointestinal tract and any pathological air trapped elsewhere.

Dalton's law states that, in a mixture of gases, the total pressure equals the ambient pressure and the pressure of each gas is related to its proportion in the mixture. Therefore increasing altitude leads to a falling oxygen tension. At 8000 feet the inspired oxygen tension will fall to 108 mmHg (from 148 mmHg at sea level) and the alveolar oxygen tension to 65 mmHg which will achieve an oxyhaemoglobin saturation of 90% in a healthy person. (3)

Current RAF Aeromedical Evacuation Control Centre Guidelines

AP3394, 3rd Edition; 2001 (1) states that following laparotomy and laparoscopic procedures AE should be deferred until normal bowel function has returned. It further states that AE should be deferred for 7-10 days if gas has been introduced into the peritoneal cavity for diagnostic purposes in order to allow gas to absorb. RAF guidelines, under the heading "Laparotomy/Air Diagnostic Procedure", state that aeromedical evacuation can be considered 48 hours post-op and that prior bowel movement is necessary (4). These are obvious precautions to avoid barotrauma related to trapped gas expansion either within the bowel or peritoneal cavity. Under the heading "General Surgical and Anaesthetic Considerations" it recommends an elapsed time of 48 hours following surgery. This precaution is presumably to avoid any complications arising from the evolution of dissolved anaesthetic gases in the tissues, such as nitrous oxide, causing decompression illness.

There are no specific recommendations for AE following bowel surgery involving an anastomosis. This author's experience of AE is that, in practice, the elapsed time following surgery involving a bowel anastomosis before AE is permitted is 10-14 days.

Gastrointestinal haemorrhage is omitted from further discussion here as all bleeding must be stopped and the patient must be

Sqn Ldr W Sapsford
MA MB BChir FRCS RAF
Honorary Research Fellow
Biomedical Sciences, Defence Science and Technology Laboratory (Dstl), Porton, Salisbury, SP4 0JQ

shown to be haemodynamically stable before AE can take place safely. In the RAF this usually means a delay of three weeks after definitive haemorrhage control.

Literature Search

A literature search was conducted using PubMed; 112 papers were generated under the phrase "Aeromedical Evacuation" and all the abstracts in English were reviewed. Any papers thought likely to contain details of AE following abdominal surgery were reviewed in full. Furthermore, the Internet more generally was searched for relevant articles. In all 18 chapters, articles and letters were obtained and reviewed that ranged from 1967-2001. There were no papers that specifically addressed the question of AE following abdominal surgery.

Results

As stated, there is no treatise or case report available on PubMed on the subject of AE following laparotomy and bowel anastomosis. Eight of the 18 papers reviewed contained no guidelines for AE at all and focussed on reviews of AE in various operations or over time periods.

The remainder of the articles highlighted various potential problems related to gaseous expansion with increasing altitude. Oxer (3) states that air within the abdomen may tend to splint the diaphragm and may lead to respiratory embarrassment and that air within the gut may give rise to colicky pain, abdominal distension and, in the unconscious patient, may cause evacuation of the lower bowel. He cites neither experimental work nor scientific evidence to support these statements.

Johnson (5) in his treatise on AE notes that the stomach and large intestine normally contain a variable amount of gas at a pressure approximately equal to the ambient pressure. The sources of this gas include swallowed air and, to a lesser extent, gas formed by the digestive processes. He notes that there is considerably less gas in the small intestine in physiologically normal circumstances. He does not mention the potentially increased amount of gas in the small intestine in the postoperative phase. He notes that: 1) gas expansion at altitude results in discomfort unless relief is obtained by belching or passing flatus; 2) colostomy patients should have a plentiful supply of bags to contain the increased passage of air and colonic contents at altitude caused by the stimulation of colonic motility by the expanding gases in the absence of physiological sphincter control and 3) in the presence of a diseased viscus caused by ulceration, such as in ulcerative colitis, tuberculous, amoebic, typhoid or peptic ulceration, it is conceivable that gas expansion could rupture the thinned wall of the viscus. He further states that patients with intestinal obstruction are susceptible to complications at altitude and that this may also apply to those who have undergone stomach or colonic anastomoses. He goes on to say that there will probably be no difficulties due to stress on the sutured stomach or intestines but that it should be borne in mind. He cites neither experimental work nor scientific evidence to support these statements.

In another contemporaneous article Johnson (6) states that while there are no absolute contraindications to AE of a patient, some conditions should be evaluated closely to determine whether or not they would withstand the stress, fatigue, and physical environment of flight. One such condition is trapped gas within any of the body cavities resulting from a surgical procedure within the previous 72 hours.

Reddick (7) reiterates the problem of trapped gas in the gastrointestinal tract, emphasising situations where there may be mechanical or functional obstruction, such as in a hernia, an ileus or in a volvulus. He speculates that post-operatively there is an increased risk of wound dehiscence caused by the expansion of trapped intraperitoneal air. He also states the theory that expanded air in the bowel may compromise anastomoses.

Ingham (8) in his article on the pitfalls of AE in Australia gives some guidelines for air transportation of patients in which he states that AE should be avoided in patients within 14 days of urological or gastrointestinal surgery. He cites neither experimental work nor scientific evidence to support this conjecture. He also speculates that those patients following recent bowel surgery or with obstructed or necrotic bowel or penetrating injuries to the bowel are at special risk.

Hansen (9) makes the general observation that patients with gastrointestinal problems suffer distension and discomfort, individuals with ulcer, diverticulitis, colostomy and postoperative abdominal patients are more likely to suffer from trapped gas in the gastrointestinal tract.

The United States Air Force Flight Surgeon's Guide (2) notes many of the potential complications above and suggests that patients with acute appendicitis, acute diverticulitis, strangulated hernias or any degree of intestinal obstruction are generally poor candidates for airlift. Furthermore it states that delay in AE should also be considered in those patients who have had recent gastrointestinal surgery to avoid increased pressure in the bowel suture line. Patients with ileus, it states, should be reported to the AE controller when evacuation by air is considered. It cites neither experimental work nor scientific evidence to support these theories.

In the Emergency War Surgery NATO Handbook (10) it is stated that experience

Table 1: List of potential abdominal problems in AE.

1) Preoperative problems
Acute appendicitis
Acute diverticulitis
Ulcerative disease (ulcerative colitis, Crohn's disease, peptic ulceration, amoebiasis)
Large / small bowel obstruction
Obstructed / strangulated hernia
Paralytic or functional ileus
Volvulus
Colostomy
The unconscious patient
2) Postoperative problems – intraperitoneal gas
Splinting of the diaphragm causing respiratory compromise
Abdominal wound dehiscence
3) Postoperative problems – intraluminal gas
Splinting of the diaphragm causing respiratory compromise
Wound dehiscence
Anastomotic compromise (leakage or dehiscence)
Expansion of air within blind loops following damage control surgery
Paralytic or functional ileus
Ulcerative disease (ulcerative colitis, Crohn's disease, peptic ulceration, amoebiasis)
Colostomy
The unconscious patient

shows that premature evacuation of casualties shortly after abdominal surgery carries a high morbidity. Patients with wounds and injuries of the abdomen are best retained at the facility in which they have undergone their initial surgical care until complications have been controlled, bowel functions have returned and the wound is healing. These requirements are seldom met in fewer than seven days.

Discussion

The articles have highlighted numerous potential problems associated with the AE of a patient with abdominal pathology. These conditions can be broken down into pre and postoperative conditions and the latter can be further subdivided into problems with intraperitoneal or intraluminal gases. (See Table 1).

All patients may experience some colicky abdominal discomfort and abdominal distension unless they can equalise the ambient and their gastrointestinal tract pressures. This will be harmless unless there is abdominal pathology such as that listed above, however, it may be sufficiently painful and alarming to cause diversion of the aircraft in the worse cases (personal communication).

The preoperative group of patients does not present a significant problem as they should undergo surgery, if possible, to correct the problem prior to AE. Other measures to deal with preoperative patients with gastrointestinal pathology are covered below. Post-abdominal surgery patients who are unconscious and those with colostomies can be dealt with by good nursing practice.

Patients who have undergone a diagnostic laparoscopy and the introduction of intraperitoneal gas will not present a significant problem in the AE system. By 48 hours following surgery, the recommended time following a general anaesthetic before AE, any significant collections of air, or more usually carbon dioxide (which is absorbed more rapidly than air), will be absorbed. Post operative laparotomy air will, likewise, have no significant presence at 48 hours. Furthermore, the abdominal wall is able to accommodate significant quantities (litres) of intraperitoneal gas with a clinically insignificant rise in pressure of no more than 10 mmHg – this is regularly observed in laparoscopic surgery. Thus, these post-operative conditions fall within the limits set out in the current RAF guidelines with the proviso that bowel function has returned.

The third group of patients (and those in the second group in whom normal bowel function has not returned) presents the most difficulty when considering AE. How long should elapse before AE is possible? In considering this issue it is worth revising the central tenet of medicine based on the Hippocratic Oath; that we must, above all, do no harm. That is, in AE, each aeromedical evacuation must be judged on its merits and in each case the anticipated benefits must outweigh the associated risks. Also, in order to achieve this, the destination medical facility should be of a higher standard of medical care than the originating facility and the standard of care during aeromedical transfer should be at least equal to that of the originating facility. In practice, however, in the difficult, austere and often dangerous military environment, tactical and logistical reasons may mandate premature AE. In this case, such a decision will still be in the best interests of each casualty even if standards of care are temporarily compromised.

In order to reduce the risks of AE in this group of patients it is also necessary to consider interventions that may reduce the volume of intraluminal gas in the gastrointestinal system. These include simple interventions in the patient and more complex alterations in the flight profile. (See Table 2).

Table 2: List of possible pre-flight interventions to reduce the risks of AE.

Patient interventions: pre-flight	
Limiting intraperitoneal air	By scrupulous air or CO2 evacuation before wound closure
Measures to limit patient anxiety	This reduces aerophagia
Nasogastric tube insertion	This will decompress the stomach of air and reduce the risk of vomiting and possible aspiration pneumonia Suction will reduce aerophagia and should be used if available
Regular anti-emetic / pro-kinetic agents	To reduce the risk of vomiting and possible aspiration pneumonia
Rectal flatus tube insertion	This may decompress the rectum and distal colon
Urinary catheter insertion	This will reduce the intraperitoneal pressure and keep a supine postoperative patient comfortable
Nil by mouth and intravenous infusion	Standard procedure in pathological gut conditions
100% oxygen administration	This diminishes gas in the abdomen (11)
Flight profile alterations	
Sea level cabin altitude	This will abolish gas expansion at the expense of a longer flight time, more turbulence, increased fuel consumption and possibly more en-route stops for crew duty hours' limitations and fuel.
Reduction of the number of stops en-route	To reduce the number of gas expansions and contraction cycles

Ideally, a doctor with experience in aviation medicine should assess all patients for consideration of AE. All such cases should be discussed with the Aeromedical Evacuation Control Centre Medical Officer.

Damage control surgery

This is a special case where patients will need AE from Role 2+ or 3 facilities following abbreviated life-saving surgical intervention designed to control haemorrhage and eliminate contamination while preventing the onset of the vicious cycle of hypothermia, acidosis and coagulopathy. These patients will be within hours of surgery and will be paralysed, sedated, intubated and ventilated with possibly multiple blind loops of stapled off bowel and a temporarily closed abdomen. The risk-benefit analysis will depend on local holding / ITU / re-operating capacity versus the risks of transfer. Each case will be judged on its merits and will frequently be in favour of AE to a facility capable of delayed and possibly definitive surgery and intensive care for a prolonged period, despite the multiple potential problems involved.

Postoperative anastomotic bursting strengths

A review of literature was undertaken to try to establish bursting pressures in animal models of postoperative colonic anastomoses. In an excellent review Christensen (12) validates the concept of bursting pressure (BP) as a test of anastomotic strength since the time of maximum pressure equals the time of anastomotic leak. He goes on to state that, in the rat model, by day 6, 60% of the tested colonic segments disrupted outside the anastomotic line. This may be due to the decreased radii at the anastomosis compared to away from the anastomotic line in the colonic segment evaluated. Application of Laplace's law determines the maximal bursting wall tension (BWT) and that, under a given pressure, wall tension will be higher outside the anastomotic line where the radius is greater. They conclude that a bursting strength test is, therefore, invalid after day 4-5 and that BWT is not a valid test of bursting strength. This is due to the variability of the anastomotic radius compared to the radius of the colonic segment and other changes in form, such as the elongation of a tested segment of colon, when inflated.

Bundy (13) compares sutured, stapled and the Biofragmentable anastomotic ring techniques of colonic anastomosis in dogs. The dogs each had three anastomoses and were sacrificed on days 0, 3, 7 and 28. Bursting pressures and bursting wall tensions were measured. In both sets of measurements the strength of the anastomosed colon at day 7 was comparable to the strength at 28 days and there was no significant difference in strength between the technique used.

Furst and colleagues (1994) evaluated bursting pressures in rat colonic anastomoses with and without corticosteroid treatment. The controls with an anastomosis showed mean bursting pressures of 145 mmHg at 6 days, 177 mmHg at 8 days and 239 mmHg at 20 days compared to 244 mmHg in normal animals without an anastomosis. Steroids significantly reduced the mean bursting pressures in all above experimental groups.

Rabau (14) studied colonic anastomoses in experimentally induced colitis in a rat model. They studied both BP and BWT and concluded that by postoperative day 7 the BP and BWT of normal colon (no colitis) with

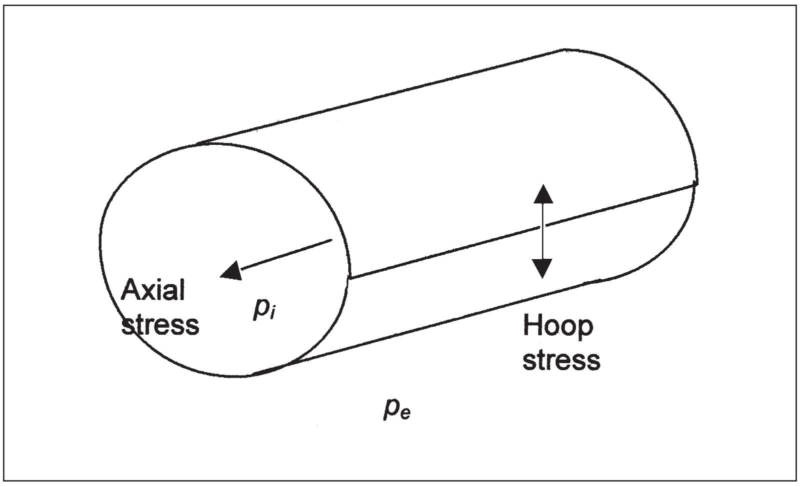

Figure 1.

anastomosis approached that of normal colon without anastomosis. In the presence of colitis the BP and BWT was significantly reduced in both the anastomosis and non-anastomosis groups but perforation occurred away from the anastomotic line, through inflamed bowel. This clearly demonstrates that the danger in ulcerative conditions of the bowel is in the ulcerative process, not in healthy anastomoses.

Edwards, in his ChM thesis (16) on the primary repair of multiple colonic injuries caused by low energy fragments, measured pig colon bursting pressures and wall tensions in normal bowel and anastomosed bowel immediately following both sutured and stapled closure, and at 6 hours, 48 hours, 5 days and 14 days postoperatively. The average leak pressure of normal (non-anastomosed segments of) pig colon was 265.2 mmHg compared to 248.9 and 205.3 mmHg respectively in stapled and sutured colon immediately after completion of the anastomoses. At 6 hours post anastomosis the leak pressures were 225.3 and 193.2 mmHg in stapled and sutured bowel whilst in normal bowel segments the leak pressure was 252.4 mmHg. At 48 hours all stapled and sutured bowel had a leak pressure greater than 73.5 mmHg or 100 cmH_2O, (the limit of the leak pressure measured). At 5 days the leak pressures were 247.3 and 220.9 mmHg in stapled and sutured bowel compared to 269.4 in normal colon. At 14 days leak pressures were 177.6 and 183.4 mmHg compared to control segments at 184.1 mmHg.

This work clearly demonstrates that high intra-luminal pressures are required to burst both normal and anastomosed bowel segments and that anastomosed bowel segments are as strong immediately after formation as they are at 6 hours to 5 days. By 14 days leak pressures were reduced, probably due to the resolution of the inflammatory reaction to the peritonitis caused by the initial fragment injury.

Some theoretical considerations

The bowel can be regarded as a thin walled cylinder if certain assumptions are made. Firstly that the stress differences across the thickness of the bowel wall are not significant and secondly that the weight of any bowel contents is also insignificant as a stress raiser. These are reasonable assumptions in bowel if the internal diameter is greater or equal to 10 times the thickness of the bowel wall and the bowel wall receives no external support. See figure 1. In this case the stresses can be calculated as follows.

Hoop stress is defined as:

$$\sigma_{hoop} = p_i.R_i / t$$

where σ_{hoop} = hoop stress (in Nm^{-2}), p_i = internal pressure (gauge) (in Nm^{-2}), R_i = inner radius (in m) and t = thickness of the bowel wall (in m) and the axial stress is defined as:

$$\sigma_{axial} = p_i.R_i / 2t$$

where σ_{axial} = axial stress (in Nm^{-2}), p_i = internal pressure (gauge) (in Nm^{-2}), R_i = inner radius (in m) and t = thickness of the bowel wall (in m).

It therefore follows that hoop stress is twice the axial stress and explains why cylinders split lengthways, rather than tear around the circumference.

The following scenario is postulated. An isolated length of bowel whose internal diameter is 10 times the wall thickness, that is closed at each end, full of air pressurised to sea level atmospheric pressure, and whose walls are unable to expand further, is placed in an atmosphere at 2500 m (8202.1 feet). It is also assumed that the entire change in pressure is transmitted to the bowel segment.

At sea level the atmospheric pressure is 101325 Pa and at 2500 m the atmospheric pressure is 74691.7 Pa, based on the International Civil Aviation Organisation standard atmosphere (17). Thus the difference in pressure across the bowel wall ($\triangle P$), or the gauge pressure is:

$$\triangle P = p_i - p_e$$

In this scenario:

$$\triangle P = 26{,}633.3 \text{ Pa}$$

To convert Pascals to millimetres of mercury multiply by 7.5006 $x10^{-3}$ giving a value for $\triangle P$ of 199.8 mmHg. Thus the maximum internal pressure that could be obtained in the absence of any bowel wall expansion or any movement of air along the bowel into other less pressurised areas is approximately 200 mmHg.

From the formulae above, the calculated stresses on the bowel wall will be:

$$\sigma_{hoop} = 26{,}633.3\ (R_i / t)$$

$$\sigma_{axial} = 13{,}316.65\ (R_i / t)$$

Thus for a segment of colon with an internal diameter of 10 times the wall thickness (corresponding to an internal radius of 5 times the wall thickness), it follows that:

$R_i / t = 5$

Thus the wall stresses will be:

$\sigma_{hoop} = 133{,}166.5\ Nm^{-2}$

$\sigma_{axial} = 66{,}583.25\ Nm^{-2}$

This is an artificial worst case scenario. Here an isolated loop of bowel at maximum diameter, filled only with air which cannot escape axially into another less compressed segment and/or out through the mouth or anus, is subjected to the full pressure change of an ascent greater than 8000 feet. The internal gauge pressure reaches 200 mmHg, a pressure that may rupture anastomoses, but is just as likely to disrupt normal bowel at any time following surgery. The wall stresses calculated in this worst case scenario also compare to stresses found in experimental work. Weatherall (18) shows that the initial yield stresses of intestinal anastomoses in pig ileum ranged between 63,000 and 86,000 Nm^{-2} in bowel with anastomoses at 30 days post surgery and 165,000 Nm^{-2} in control ileal segments. This worse case scenario is, however, unlikely in any casualty following a bowel anastomosis except, possibly, in the case of damage control surgery.

Conclusions

There is nothing in the medical or RAF literature to support the statement that a period of 10-14 days should elapse following abdominal surgery before AE. The maximum period advised in the RAF literature is 7-10 days following laparotomy and laparoscopic procedures if gas has been introduced in order to allow it to absorb. Sea level cabin altitude is advised if AE is imperative (1). This is, however, contradicted in the RAF guide to the AE service that states that AE can be considered at 48 hours if bowel movement is present (4).

The USAF Flight Surgeons Guide (2) recommends an unspecified delay following gastrointestinal surgery to avoid increased pressure on the suture line. The Emergency War Surgery NATO Handbook (10) states that following bowel surgery the conditions for AE are seldom met in fewer than seven days. It also states that evidence shows that premature AE of casualties after abdominal surgery carries a high morbidity. It does not, however, cite any evidence for this statement.

Most authors recognise the theoretical risk to the bowel suture line and make no recommendations regarding the timing of AE. Ingram (8), however, recommends a delay of 14 days whilst Johnson (5) speculates (without experimental work or citing scientific evidence) that there will probably be no difficulties due to stress on a sutured stomach or intestine.

The animal experimental work reviewed suggests that by postoperative day 4-5 bursting pressure of the colon is not relevant in the assessment of anastomotic strength (12). This is because the colon is likely, at the pressures required, to disrupt away from the anastomotic line. The other studies confirm this finding and suggest pressures of 145-250 mmHg are required to disrupt colonic anastomoses postoperatively, no matter the anastomotic technique used (13, 16). Steroid treatment and colitis reduce this bursting pressure (14, 15).

The theory discussed suggests that the maximum internal (gauge) pressure that it is possible to achieve in the worst case, highly artificial, circumstances above, is 200 mmHg. This pressure and the calculated wall stresses are of sufficient magnitude to be able to disrupt bowel with or without an anastomosis. However, the conditions necessary are unlikely even to be met in the AE of a casualty after damage control surgery in which multiple blind loops of air filled bowel are present, and only then if the cabin is pressurised to the maximum cabin altitude permissible of 8000 feet.

This author believes that with the pre-flight patient interventions above it should be possible to perform AE in most patients in fixed wing, pressurised aircraft with a cabin altitude maximum of 8000 feet at any time after 48 hours following abdominal surgery with or without one or more bowel suture lines. The absence of normal bowel movement should not be considered a contraindication; rather, the presence of an ileus or continued bowel obstruction should indicate a relative need for delay or re-operation. At 48 hours, in the presence of a normal bowel action, AE is possible in all postoperative abdominal patients. This applies to all patients being moved to a facility with a higher standard of care than the originating facility and where the standard of care during AE is no worse than that in the originating facility. Finally every AE must be judged on its merits and there is no absolute contraindication to movement of patients by air.

References

1. Leaflet 10-01 Introduction to Aviation Medicine AP3394 3rd Edition 2001.
2. Sanger, A, Stoner P Global Aeromedical Evacuation USAF Flight Surgeons Guide: Chapter 19.
3. Oxer HF. Aeromedical evacuation of the seriously ill. *Br Med J.* 1975; **3(5985):** 692-4.
4. Aeromedical Evacuation Control Centre. A Guide to the Royal Air Force Aeromedical Evacuation Service 2001.
5. Johnson A Jr. Treatise on aeromedical evacuation II: Some surgical considerations. *Aviat Space Environ Med.* 1977; **48(6):** 550-4.
6. Johnson A Jr. Two years of routine patient movement in the USA (Jan 1974 – Dec 1975). *Aviat Space Environ Med.* 1977; **48(5):** 451-3.
7. Reddick EJ. Aeromedical evacuation. *Am Fam Physician.* 1977; **16(4):** 154-60.
8. Ingram PN. Pitfalls of aeromedical evacuation. *Aust Fam Physician.* 1983; **12(12):** 881-3.

9. Hansen PJ. Safe practice for our aeromedical evacuation patients. *Mil Med.* 1987; **152(8):** 281-3.
10. United States Department of Defence Emergency War Surgery NATO Handbook: Part III: General Considerations of Wound Management: Aeromedical Evacuation
11. Loder RE. Use of hyperbaric oxygen in paralytic ileus. *Br Med J.* 1977; **i:** 1448-9.
12. Christensen H, Langfelt S, Laurberg S. Bursting strength of experimental colonic anastomoses A methodological study. *Eur Surg Res.* 1993; **25(1):** 38-45.
13. Bundy CA, Jacobs DM, Zera RT, Bubrick MP. Comparison of bursting pressure of sutured, stapled and BAR anastomoses. *Int J Colorectal Dis.* 1993; **8(1):** 1-3.
14. Furst MB, Stromberg BV, Blatchford GJ, Christensen MA, Thorsen AG. Colonic anastomoses: bursting strength after corticosteroid treatment *Dis Colon Rectum.* 1994: **37(1);** 12-15.
15. Rabau M, Eyal A, Kluger Y, Dayan D. Bursting pressure in anastomotic healing in experimentally induced colitis in rats. *Dis Colon Rectum.* 1998: **41(4);** 468-72.
16. Edwards DP. Primary repair of multiple colonic injuries Thesis submitted to the University of Manchester for the degree of ChM in the faculty of medicine 1998.
17. Tennent RM. (Ed) Science Data Book Oliver & Boyd Published 1971 Eighth Impression 1983; ISDN 0 05 002487 6.
18. Wetherall AP, Cooper GJ, Ryan JM, Taylor DE, Howell GP, Rice P. Use of disposable skin staplers for bowel anastomosis to reduce laparotomy time in war. *Ann R Coll Surg Engl.* 1992; **74(3):** 87-90.