SPECIAL ARTICLE

Aviation and Cardiac Surgery: What Can Be Tranferred from One to the Other To Improve Safety?

Aviación y cirugía cardíaca: ¿Qué se puede trasladar de una a otra para mejorar la seguridad?

ROBERTO BATTELLINI[1]

INTRODUCTION

In 1984, Perrow states his theory of "Normal accidents" and describes complex interactions, where catastrophes are unavoidable in tightly coupled complex systems. He predicts that failures will occur in many unpredictable ways. The failure of a component may have multiple downstream effects. In these systems there are few possibilities of substituting or reassigning personnel due to their high specialization, closed personal contact and scarce understanding of some processes. There is a point in the organization, which, once transgressed, results in the collapse of the following level. When this is reached, a change, insignificant in itself, may occur, but which may lead to a massive, fast and catastrophic transformation of the system. (1) Aviation accidents or complicated patients who suffer cycles of errors or cardiopulmonary bypass errors (CPB) caused by forgetting heparin administration before its initiation, are examples of this type of accidents. The integral analysis of accidents shows that these result from the alignment of conditions and events, each of which is necessary, but none alone is enough to provoke it.

TWO EXAMPLES RELATING AVIATION AND CARDIAC SURGERY. IN BOTH, THE ACTORS DO NOT UNDERSTAND THE EXISTING COMPLEXITY DUE TO LACK OF A SYSTEMIC APPROACH

1. Flight Airbus 330 Rio-Paris AF 447/2009. During this flight a storm froze the speed sensor (Pitot tube), disconnecting the automatic pilot. The two young pilots in charge acted out of synchronization, did not ask for help and the plane crashed. The accident was finally explained by the black box. The error resided in the lack of man-machine communication: the pilots in charge were not trained for this unknown critical situation (AF 447 Final report 2012 www.bea.aero/enquetes/flight.af.447 / rapport.final.en.php.)
2. In 1980's, a series of patients operated on in a local institution, who were already awake and neurologically active, were weaned from mechanical ventilation. After blood sampling for gas analysis and catheter purge, the patients suffered from convulsions and coma. An external investigator was invited to clarify the problem, which had initially been attributed to failures in cardiac oxygenation or in CPB. The investigator, however, found that the introduction of a new method of postoperative arterial catheter purge introduced bubbles at a pressure so high that it surpassed that of the aortic arch, injecting them into the carotid arteries.

COMPLEXITY IN THE OPERATING ROOM

The operating room is a setting characterized by a high degree of complexity regarding human-technological and human-human interfaces. The procedures require the coordinated efforts of multiple groups, working under stress. Here, contrary to aviation, the human composition is continually changing. Hence, communication issues may arise with catastrophic outcomes. During CPB, in case low flow or cardiac arrest is needed, a minimal error may be fatal.

It has been confirmed that cardiac surgeons take a life or death decision every 10 s during an operation. Most would agree that 75% of results are attributed to correct decisions (for example, air removal from the heart) and 25% to technique (for example, stitches in the coronary artery). Marvil, in 1917, suggests keeping a permanent situation awareness, defined as the degree of precision with which perception copies reality. (2) Transesophageal echocardiography is similar to flight controllers, since it allows the step by step control of functional results during surgery.

SIMILARITIES AND DIFFERENCES BETWEEN CARDIAC SURGERY AND AVIATION

The former is practiced with an "open door" to many people, whereas the latter, is conducted within a closed cockpit. The number of aircraft staff is lower than that is an operating room: while 3 pilots work in a jet cockpit, more than 10 persons of different specialties do so in the operating room, increasing the complexity as the number of people increases. Surgical teams are heterogeneous, including their modes of communication; however, complementarity is greater due to

[1] Honorary Chief of Cardiovascular Surgery, Hospital Italiano, Buenos Aires.

subspecialties. The intricacy of human relationships increases exponentially and not linearly with the number of actors involved, decreasing the quality of leadership (Pendharkar, 2007). (3) The lack thereof may hamper the recovery of errors in critical circumstances. Cardiac surgery is "aviation and something else": the human being is more complex than an aircraft. Both fields require celerity to manage situations of crisis or emergency, sometimes, with little information. Cardiac surgeons often face these situations, frequently aortic ruptures or dissections. In the surgical emergency, it is necessary to "fly with bad weather", differentiating it in part from aviation, even though emergencies may arise during the flight. An example of excellence in aviation critical management was the pilots' conduct during US Airways flight 1549. The commander trained all his life for a contingency that perhaps would never happen, the predictable of the unpredictable: to land in the water (Eisen, 2009). (4)

In the cockpit, the function of the pilots is to a certain degree overlapped (they are interchangeable); in the operating room, due to organizational and economic reasons, this does not always occur. If the plane falls, the pilot falls with it. In commercial aviation, many lives are at risk during a flight; in surgery, only one. Airplane accidents are public, highly visible and generate demands for investigation and repair. As a result, more resources are destined for research, whereas iatrogenic adverse events are kept in reserve (Bogner, 1994). (5)

TRANSLATIONAL MEDICINE FROM AVIATION TO CARDIAC SURGERY: AIRWAY SAFETY TAKEN TO THE PATIENT

1. Incident reporting (CHIRP) and observational audit (LOSA)

The impossible safety rate reached by commercial aviation (in USA fatal accidents are minimal: 0.017/100,000 flights/year) seduces translational medicine, especially when the US Institute of Medicine estimates that each year between 44,000 and 98,000 persons die due to medical errors (Hemreich, 2000). (6) The science of human factors, cornerstone of aviation safety, has not yet found its place in Medicine, but could greatly change the understanding and execution of medical decisions (Schappell, 2007, Eltorai, 2018) (7, 8) The factor associating aviation and medicine that is indispensable or complex enough is the human error. In the current era, the new technological wonders have created an expectation of total perfection. The patients, who have the understandable need of considering the physician to be infallible, have colluded (agreed) with them to deny the existence of error and reject uncertainty, sometimes the only certain thing. Analyzing the cardiac surgery system, Wiegmann postulates that error is related with disruptions in the surgical flow produced by communication mistakes, external distractions and hardware faults. (9)

The report not only of accidents, but near misses is essential in the CHIRP (Confidential Human Factors Incident Reporting) program. This allows making no punitive reports (Eidt, 2012). (10) Helmreich, a psychologist dedicated to human factors in aviation and surgery, has observed numerous surgeries and recorded suboptimal communication and workteam instances, similar to those found in the cockpit. (6)

Another element that can be transferred to surgery is LOSA (Line Operations Safety Audit) an observational audit project developed by Helmreich (www.psy.utexas.edu/psy/helmreich/nasaut.htm), where expert observers sit in the cockpit of normal flights to register threats to security, errors and their management. These results confirm an average of two threats and two errors per flight, with an unexpected over half of errors due to violation of established regulations.

2. Sterile cockpit protocol

Aviation has instituted a mandatory "sterile cockpit" protocol during periods of high mental stress, that is, take-off and landing. These are standardized communication, phrasing and call back protocols to reduce ambiguity. This protocol was transferred to the Mayo Clinic in 2010, where eight critical events were defined during CPB and a NASA-like protocol was implemented (NASA Task Load Index). Thus, altered communication decreased significantly (Wadhera, 2010). (11) It was emphasized that "non-verbal" actions, such as aortic clamping and unclamping be reduced when communicating them. The authors concluded that, different from aviation, cardiac surgery has no exact time that can be conveniently defined as the main high mental risk and stress period from the point of view of the complete human team. Figure 1, taken from Wadhera, shows the difference in mental load in the operating room; contrary to aviation, the highest stress for each component of the team occurs at different moments.

The surgeon should highlight focusing on critical events: heparin administration/CPB initiation, clamping/cardioplegia/unclamping/CPB weaning, more than in critical periods.

3. "Threat and error" NASA model

The pediatric surgeon Hickey suggests considering each surgery as a flight. He analyzed 524 flights/patients and found 763 "preoperative threats" (atypical morphology, multiple lesions, comorbidities) in 72% of cases. He recorded 430 proficiency or judgment errors, which were consecutive in 67% of cases and in 21% of the total number of patients, subsequent cycles of additional error were produced. These cycles, which contained multiple mistakes, were associated with surgical complications and, even, death in 1.3% of cases. He concluded that an unsolved error leads to cycles of errors and severe complications (Hickey, 2015). (12)

4. Mission analysis: Crew resource management (CRM)

At the beginning of the 80's, due to several aviation disasters, The Crew Resource Management (CRM)

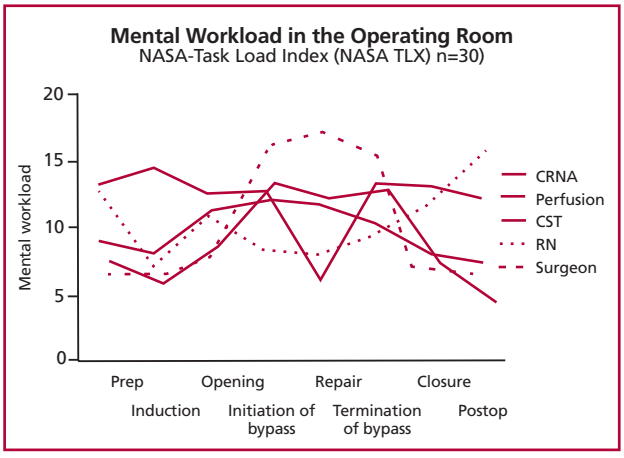

Fig. 1. Results of National Aeronautics and Space Administration Task Load Index (NASA TLX) show widely divergent cognitive workload measure durin course of typical case. CRNA, certified registered nurse anesthetist; CST, certified surgical technologist; RN, registered nurse; Prep, surgical preparation; Postop, postoperative.

was developed in the USA to improve performance and promote safety. These improvement strategies can be transferred to surgery. In 2007, McGreevy suggests two steps. In the first part or briefing (instructions), the pilots explain beforehand not only what is going to be done or expect that will happen, but also the measures to be taken in each case. A surgical example would be: if after a sternotomy a patient decompensated, how to immediately start CPB. The second step, or debriefing (reflections) is a deep introspection about what went well and what did not, to avoid repeating the error. (13)

5. Simulators

In aviation, each major incident is followed by the simulation of its causes to avoid another posterior event; this has become part of the training and the hardware is redesigned. In surgery, complications are considered a routine and besides being mentioned in a clinical seminar, they are not reported. Simulators constitute a structured part of training in aviation and in surgery it is progressing thanks to the former. Practice is without risks and surgeons develop skills to recover from the error. Pilots do not fly in a plane for which they have not been trained in a simulator, and in which they are periodically examined. In cardiovascular surgery, a surgeon must operate, in many instances, a case for which he has not been trained. Unfortunately, the complexity of biological systems is almost impossible to "simulate" with the same level of realism. The future in surgical education are hybrid simulators combining plastic material and biological organs. Gaba, pilot and leader of simulation in Medicine, believes that although aviation concepts and practices cannot be directly transferred, translation or adaptation is possible and necessary (Gaba, 2011). (14)

SUMMARY AND CONCLUSIONS

1. The possibilities of error in cardiac surgery are more unpredictable.
2. In aviation, a better systematization of procedures has been implemented to improve safety, and the inevitability of error is accepted.
3. Physicians tend not to acknowledge error, or fatigue, and together with patients they make a deal (collusion) to deny the former.
4. Transferring the systematics mentioned for aviation to surgery helps to come close to their safety standard, though it does not completely solve the problem.
5. Investigating the human factors affecting error is essential in surgery.

Conflicts of interest

None declared.

(See authors' conflicts of interest forms on the website/ Supplementary material).

REFERENCES

1. Perrow C. Normal Accidents: living with high risk technologies. New York basic books 1984. En: Human error, Reason 1990. Cap. 7 Latent errors and systems disasters.
2. Marvil P, Tribble C. Lessons from crew resource management for cardiac surgeons. Heart Surg Forum 2017;20:E077-81. http://doi.org/gbghwt
3. Pendharkar C, Parag & Rodger, James. An empirical study of the impact of team size on software development effort. Information Technology and Management. 2007;8: 253-62. http://doi.org/cwzqtx
4. Eisen LA, Savel RH. What went right: lessons for the intensivist from the crew of US Airways Flight 1549. Chest 2009;136:910-7. http://doi.org/cwzqtx
5. Bogner MI, Helmreich RL, Schaefer HG. Team performance in the operating room. In: Bogner M, ed. Human Error in Medicine. Hillsdale, NJ: Laurence Erlbaum 1994.
6. Helmreich RL. On error management: lessons from aeronautics. BMJ 2000;320:781-5. http://doi.org/dhts97
7. Schappell S, Wiegmann D. The human factor analysis and classification system. HFACS levels. Human Factors 2007;49:227. http://doi.org/fmpxrb
8. Eltorai AS. Lessons from the sky: an aviation-based framework for maximizing the delivery of quality anesthetic care. J Anesth 2018;23. http://doi.org/c9dx
9. Wiegmann D, ElBardissi AW, Dearani JA, Daly RC, Sundt TM. Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. Surgery 2007;142:658-65. http://doi.org/bg9k83
10. Eidt JF. The aviation model of vascular surgery education. Presidential address. J Vasc Surg 2012;55:1801-9. http://doi.org/c9h2
11. Wadhera R, Hendrickson-Parker S, Burkhart HM, Greason KL, Neal JR, Levenick K, et al. Is the sterile cockpit concept applicable to cardiovascular surgery intervals or critical events? The impact of protocol-driven communication during cardiopulmonary bypass. J Thorac Cardiovasc Surg 2010;139:312. http://doi.org/c6z8d8
12. Hickey EJ, Nosikova Y, Pham Hung E, Gritti M, Schwarz S, Caldarone C, et al. National Aeronautics Space Administration "threat and error" model applied to pediatric cardiac surgery: error cycles precede 85% of patient deaths. J Thorac Cardiovasc Surg 2015;149:496-507. http://doi.org/f642m7
13. McGreevy J. Briefing and Debriefing in the operating room using fighter pilot crew resource management. J Am Coll Surg 2007;205:169-76. http://doi.org/b338gj
14. Gaba D. Have we gone too far in translating ideas from aviation to patient safety?. NO. BMJ 2011:342:c7310. http://doi.org/b83qmv