Transferring Aviation Practices into Clinical Medicine for the Promotion of High Reliability

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BACKGROUND: Aviation is a classic example of a high reliability organization (HRO)—an organization in which catastrophic events are expected to occur without control measures. As health care systems transition toward high reliability, aviation practices are increasingly transferred for clinical implementation.

METHODS: A PubMed search using the terms aviation, crew resource management, and patient safety was undertaken. Manuscripts authored by physician pilots and accident investigation regulations were analyzed. Subject matter experts involved in adoption of aviation practices into the medical field were interviewed.

RESULTS: A PubMed search yielded 621 results with 22 relevant for inclusion. Improved clinical outcomes were noted in five research trials in which aviation practices were adopted, particularly with regard to checklist usage and crew resource-management training. Effectiveness of interventions was influenced by intensity of application, leadership involvement, and provision of staff training. The usefulness of incorporating mishap investigation techniques has not been established. Whereas aviation accident investigation is highly standardized, the investigation of medical error is characterized by variation.

DISCUSSION: The adoption of aviation practices into clinical medicine facilitates an evolution toward high reliability. Evidence for the efficacy of the checklist and crew resource-management training is robust. Transference of aviation accident investigation practices is preliminary. A standardized, independent investigation process could facilitate the development of a safety culture commensurate with that achieved in the aviation industry.

KEYWORDS: high reliability, high reliability organizations, National Transportation Safety Board, accident investigation, patient safety.

Powell-Dunford N, McPherson MK, Pina JS, Gaydos SJ. *Transferring aviation practices into clinical medicine for the promotion of high reliability*. Aerosp Med Hum Perform. 2017; 88(5):487–491.

High reliability organizations (HROs) are defined as organizations in which catastrophic events would be expected to occur on a routine basis in the absence of rigorous control measures.[21] Consequences of even a single error could be disastrous—aviation and air traffic control, spaceflight, and nuclear power plants are just a few examples. Key characteristics of the HRO include preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise.[35] HROs are conscientious that failures can happen and avoid generalizations, looking instead for detailed root causes. Leaders of HROs listen to those on the front lines and all employees look at mistakes as opportunities to learn, deferring to expertise rather than rank or position. **Table I** further characterizes the cardinal features of an HRO, which are strongly embedded within the aviation industry.

Aviation, a recognized model for high reliability, was originally plagued by extremely high mishap rates. For example, U.S. air mail pilots initially had a 30% mortality during the advent of civil and military aviation.[3] By 2001, aviation was recognized as a far safer form of transportation than the automobile, with 13.9 deaths per million flights.[2] Despite low fatality rates, the aviation community pushed for further reductions, resulting in only 1.6 deaths per million flights over the next decade with a clear industrial goal of zero preventable harm.[2] Contrary to this model, the number of accidental patient deaths experienced within the healthcare industry has not fallen over the past 30 yr, with up to 400,000 preventable deaths per year estimated most

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This manuscript was received for review in July 2016. It was accepted for publication in December 2016.

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DOI: https://doi.org/10.3357/AMHP.4736.2017

Table I. Cardinal Features of the High Reliability Organization (HRO).

STRICT CULTURE OF EXCELLENCE*[,36]	CREATING AN HRO[2,35]
Integrity: eliminate "sins of commission" (deliberate departures from protocol)	Collective mindfulness
Depth of knowledge: rigorous education and training	Preoccupation with failure
Procedural compliance: extensive inspections	Reluctance to simplify
Forceful backup: empowerment of the crew	Sensitivity to operations
A questioning attitude: alert for anomalies; satisfied only with thorough answers	Commitment to resilience
Formality in communication: prescribed processes	Deference to expertise

* Rickover H. Quotes by Admiral Hyman Rickover. [Accessed 2 Jan. 2016]. Available at http://govleaders.org/rickover.htm.

recently. Serious harm is estimated to be 20-fold higher in incidence than fatal harm.[19] As health care systems transition toward HROs, core aviation practices have been evaluated for clinical implementation. In particular, checklists, crew resource management (CRM), and mishap investigation are human factor based aviation practices that have the potential to improve clinical safety outcomes.

From the HRO standpoint, the checklist embodies deference to expertise and preoccupation with failure—acknowledging that mistakes are an integral part of the human condition and individuals must defer to the competence of those who have outlined the right steps to a procedure. The checklist was developed as a result of the catastrophic test demonstration of the B-17 bomber prototype. In this mishap, one of the Army's top instructor pilots was killed after a failure to release a locking mechanism, almost leading to the scrapping of this aircraft as 'too complex to fly.' Test pilots convinced leadership that the B-17 could be safely flown using a checklist. As a result, the initial B-17 bomber fleet recorded over 1.8 million accident free hours. The B-17 was thereafter mass-produced and flown decisively during WWII.[9] CRM was developed after investigations revealed that human error is responsible for the majority of mishaps. CRM has been mandated enterprise wide within the aviation community because of its proven effectiveness in behavior modification.[8] CRM addresses negative impacts to performance, briefings, leadership, and cross checking. Initially viewed by many as a challenge to pilot autonomy, CRM became established as a highly effective method of changing behaviors, with numerous instances of accidents averted entirely or characterized by far fewer fatalities than could normally be expected following mandatory implementation.[10]

Aviation mishap investigation and reporting is done with a focus on safety—not to "name, blame, and shame" individuals, but rather, to identify weaknesses or gaps within "the system" in order to design safeguards, controls, or regulatory parameters to improve safety. Accident investigation is characterized by reporting at the lowest possible levels, analysis of all causal or contributing factors (including potential issues of improvement even if unrelated to causality), and ensuring dissemination of lessons learned across the entire community. Reporting in aviation is anonymous, standardized, and highly encouraged. Analysis of mishaps in aviation is a highly regulated process. U.S. Army doctrine, for example, exceeds 150 pages of guidance on how aviation mishap investigations are to be conducted.[7] Aviation mishap investigation is characterized by centrally trained investigators, safety centers, and deployable teams of experts.

Healthcare is also plagued by a fragmented and decentralized lack of standardization with respect to investigation with wide variation in reporting systems. In contrast to aviation, however, the fear of litigation and stigma historically has limited reporting in clinical medicine. There is scant regulatory guidance for the investigation of medical error.

METHODS

A two-staged literature view was conducted. A preliminary PubMed search using the terms 'aviation,' 'crew resource management,' and 'patient safety' was undertaken in order to analyze the effectiveness of adopting aviation based practices into health care systems. A secondary search was conducted using search terms 'NTSB,' 'aviation,' 'accident investigation,' and 'healthcare' in order to identify further areas in which aviation practices have been adopted within the healthcare industry. A convenience sample of literature authored by physicians with concurrent professional roles of military or commercial pilots, literature advocating for the adoption of specific aviation practices, and/or demonstrating patient-oriented outcomes were selected for inclusion. Follow-on interviews were conducted with subject matter experts from multiple nations involved in adoption of aviation practices into the medical field.

RESULTS

The literature review yielded a total of 621 results with 22 relevant for inclusion on the basis of pilot-physician authorship, advocacy for adoption of specific aviation practices, and/or the reporting of improved patient-oriented outcomes associated with the incorporation of aviation based practices. Improved clinical outcomes were noted in five research trials in which aviation practices were adopted, particularly concerning checklist usage and CRM training. The effectiveness of interventions was influenced by intensity of application, leadership involvement, and provision of staff training. The usefulness of mishap investigation techniques has not been established due to the preliminary nature of their incorporation into the healthcare system. Subject matter experts have advocated for independent medical error investigative bodies in both the United Kingdom and the United States.

To date, checklists appear to have the most evidence for successful incorporation into clinical practice. When 10-d catheter-related infection rates fell from 11 to 0% over 3 mo at the Johns Hopkins Intensive Care Unit (ICU) in association with deployment of a 5-item checklist, further assessment was conducted across 108 ICUs in Michigan. Infection rates in these locations subsequently fell by 66% over the course of 18 mo,[28] with significant decrease in overall hospital mortality in Michigan compared with the surrounding area[22] and an end result of over $200 million and 1500 lives saved.[31] The program was characterized by nurse empowerment, stocking of adequate supplies, and executive involvement. In 2006, researchers developed a World Health Organization surgical checklist which significantly lowered surgical complications and mortality rates across a broad range of hospitals when conducted in conjunction with leadership involvement, program monitoring, and team communication training.[12] However, these results were not replicated in over 100 facilities in which the checklist was simply mandated—most likely due to the lack of team training or a comprehensive safety program.[34] Despite documented successes with the checklist, the 2010–2011 longitudinal study 'Surgical Checklist Implementation Project' revealed that the entire checklist was completed in only 62% of facilities, with direct negative impact on post-op complications.[25] Aspects of CRM training were deliberately incorporated along with patient simulator technology into anesthesiology training in the 1990s through a program known as Anesthesia Crisis Resource Management.[4,16] The list below notes specific Aviation CRM imperatives realized for clinical application.

- Delegation of tasks and assignment of responsibilities
- Priority assessment
- Monitoring/cross checking
- Use of information
- Communication
- Leadership
- Problem assessment
- Avoidance of preoccupation—Failure to consider an alternative to tracheal intubation, a harmful procedural preoccupation, is to be contrasted with an HRO's beneficial preoccupation with failure.

Below is an outline of the structure of this training, which came to be replicated in other facilities over time.

- Human performance, decision-making, and human error in the dynamic world of anesthesia.
- Videotape screening of the simulator re-enactment of the crash of Eastern Airlines Flight 401.
- Videotape screening of an actual anesthetic mishap (with permission of nonidentifiable anaesthesiologists).
- Discussion of both successful and unsuccessful aspects of crisis management.
- Crisis management scenarios with debriefing.

Mark Haerkins, a board-certified intensivist and retired Royal Air Force pilot, founded a Dutch organization committed to patient safety and envisioned the implementation of CRM in the ICU setting. CRM are leadership, decision-making, and communication procedures used within high-risk environments in order to reduce the risk for error, to trap errors committed, and to mitigate the consequences of error.[15]

CRM training has been determined to be effective in changing attitudes and behaviors and has been established as an annual training requirement for commercial flight crews. In a 3-yr analysis, Haerkins demonstrated that intensely applied CRM training resulted in significant survival benefit.[11] These findings were replicated at 108 facilities and demonstrated a 'dose-response' curve in which more training resulted in more lives saved. Specifically, for every quarter of the training program, a reduction of 0.5 deaths per 1000 procedures occurred.[27] Although CRM training reduced the incidence of wrong site surgery and retained foreign bodies in one teaching hospital, incidence of these complications reversed within 14 mo after discontinuation of CRM training, underscoring the need for a sustained commitment to this practice.[30] Although understudied in this regard, CRM as part of a larger human factors program integrated with quality assurance activities is theorized to increase efficiency, safety, and job satisfaction.[15] CRM is most established in the operative, intensive care, and air ambulance/transitions of care environments. The UK Royal Air Force Critical Care Air Support Team has successfully implemented a monthly CRM briefing followed by a simulated mission exercise, resulting in improved team cohesion, erosion of rank barriers, and enhanced communication.[17] Most recently, CRM implementation across a major academic medical center's three hospitals and three campuses resulted in statistically significant increases in teamwork, communication openness, organizational learning, and error reporting over 2 yr, demonstrating the ability of CRM training to improve safety culture across a system of diverse inpatient and outpatient organizations.[14]

While employment of the checklist and adoption of CRM have been well described in the medical literature, gaps between mishap and medical error investigation are just beginning to be addressed. Analysis of 138 medical journals analyzing medical error investigation revealed that there is wide variation on how root cause analysis is conducted, limited references to training, and little to no discussion of how to disseminate lessons learned.[37] Permanently sealing medical records as part of medical malpractice litigation agreements greatly jeopardizes lessons learned sharing and actually increases the risk for recurrence of the same sort of medical error. In aviation, 'all airmen' notifications are often generated as a result of mishaps for enterprise-wide dissemination of important and timely information, and it is expected that safety enhancing technologies will evolve to address weaknesses identified through the mishap investigation process. Although the Joint Commission recently established a sentinel event database, the lowest level employee typically does not know about medical errors within a given medical facility, and there are fears about litigation and uncertainty if patient safety reports will result in any changes. As a best practice, The Michigan Quality Improvement Consortium facilitates data and best practice sharing across 18 healthcare and health insurance organizations throughout the state.[26] KJ Somer, a Boeing 747 instructor pilot and practicing urologist, has called for a 'cause not blame' approach, shared safety culture, continual learning, and punishment-free reporting within the health care industry as a whole.[33] Other researchers in quality assurance have also called for the utilization of aviation mishap archetypes and investigation techniques. Singh et al. determined that medical error is under-studied and that system error, cognitive error, and situational awareness must be evaluated in a similar fashion as the aviation mishap investigation process.[32]

Despite these gaps, some progress has been made concerning adoption of aviation mishap investigation practices. A human factors expert became involved in the Manitoba Pediatric Cardiac Surgery Inquest after a chance encounter between a pilot and a nurse on the investigation team; in this case, noise and fatigue were considered to be contributors to some of the deaths in the facility.[5] A medical investigation course was subsequently developed at the University at Calgary in order to provide healthcare investigators with a standardized method of investigation and one that routinely included consideration of human factors.[13] The U.S. Air Force routinely employs aeromedical physiologists in significant medical investigations in order to enable thorough human factor consideration (BG Sean Murphy, Medical Corps Chief USAF and Col. Charlie Carlton, BSC Deputy Command Surgeon USAF; personal communication; 6 June 2016). The U.S. Air Force Medical Operations Agency (AFMOA) is in the process of adopting aviation mishap styled training for medical investigators and is in the preliminary phases of incorporating searchable medical error data into existing aviation mishap investigative data repositories (Col. David Williams, Chief, Clinical Quality AFMOA; personal communication; 6 June 2016). The U.S. Army Medical Command's HRO Directorate is in communication with the Army's Combat Readiness Center (Safety Center) for subject matter expertise as it fields a centralized Quality and Safety Center for optimized medical investigation (COL David C. Romine, Command Surgeon, U.S. Army Combat Readiness Center and COL Joseph S. Pina, OTSG HRO Directorate; personal communication; 2 June 2016).

Although attempts to establish a medical investigative authority across the United States were thwarted,[6] the U.K. has recently mandated a medical investigative organization for the National Health Service[18] after considerable consultation with the Air Accident Investigation Branch and a call to action within the medical literature.[23] The Chief Investigator (Branch Head) of the civilian Air Accident Investigation Branch has furthermore been selected to lead the UK's first Health Service Accident Investigation Branch.[1] Unfortunately, research has not yet been proposed to assess the efficacy of these mishap adoptive initiatives. Such a proposal and a more complete analysis of applied aviation mishap investigation techniques will be addressed in a future manuscript.

DISCUSSION

The previous few decades have witnessed unprecedented change among health care systems with extraordinary advances in medical care. Yet the topics of patient safety and medical error have also emerged as a consequentially grave and significant subject within the complex health care industry.[20,24] With respect to medical error, the ground breaking 1999 Institute of Medicine report, "To Err Is Human," beseeches, "The status quo is not acceptable and cannot be tolerated any longer. Despite the cost pressures, liability constraints, resistance to change and other seemingly insurmountable barriers, it is simply not acceptable for patients to be harmed by the same health care system that is supposed to offer healing and comfort." The report specifically highlights aviation as an industry that has been successful in improving safety.[20]

Promising gains in patient safety have been achieved through the implementation of the checklist and CRM. However, these gains are predicated on intense enterprise-wide implementation with stakeholder buy-in and leadership endorsement, as well as a full commitment to implementation of all HRO qualities (Table I). Checklists that were legally mandated without education, leadership involvement, or oversight failed to achieve improvements in either postoperative complications or survival. When fielded with education and oversight, the WHO surgical check list resulted in improvements in postoperative complication rates and survival rates regardless of whether it was implemented in resource-rich or resource-poor locations. Without oversight on implementation, wide variation exists with regard to the extent of checklist use.

CRM training demonstrates a dose-response effect in which further reductions in complication rates occur with increased frequency of training. Importantly, improvements in complication rates erode after discontinuation of CRM training, highlighting the importance of training sustainment. Mishap investigation techniques such as standardization in the training of investigators and the investigative process itself, as well as the presence of an independent centralized investigative organization, are still in development. Research must be undertaken to validate the efficacy of such practices, which hold great promise.

The delivery of care is an exceedingly human endeavor and humans are inherently fallible. Highlighting a system approach to human error, Reason notes that "…though we cannot change the human condition, we can change the conditions under which humans work."[29] It has taken decades with a price in both blood and treasure, but the aviation community has addressed much of the fallacy of the human condition using processes such as the checklist, CRM, and accident investigation. Will medicine continue to learn from this? Can it afford not to?

ACKNOWLEDGMENTS

The authors wish to thank Maj. Stephen Turner, Army Air Corps Operations Investigator Defence AIB (Air); Jan Davies, M.D., FRCPC, FRAeS; Charles Vincent, Prof. of Psychology, University of Oxford; Carl Macrae, Prof. of Psychology, University of Oxford; COL David C. Romine; Col. David Williams; Col. Charlie Carlton; and BG Sean Murphy for substantial insights during the development of this manuscript.

The views and opinions expressed in this manuscript do not reflect those of the U.S. Army or the U.S. Department of Defense.

This manuscript is dedicated to all our patients. May we continually aim for zero harm in their care.

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