were controllable were considered an error. This is in line with the seminal publication of Leape and colleagues 20 years ago.

Dr Paul Kirshbom *(Atlanta, Ga)*. I was wondering with this very nongranular presentation if more granular analysis of your data presented you with any opportunities to take action. Did you identify a commonality in your ICU errors, for example, drug delivery in a large majority that could be affected by a change in your drug-delivery system or any other commonality you could change in the future?

Dr Jacques. Yes, we have identified areas to target. That was the ultimate goal, but I haven't been able to detail that aspect in the presentation. In the postoperative period, ''hinge points'' are important. We know that in the intensive care and anesthesia literature, all the transition points, such as transferring, transporting, and extubating the patient, are important periods. In our study, ''hinge points of importance'' are timing of delayed chest closure, timing of extubation, transfer to the ward, and the period surrounding the discharge of the patient. These are the most important areas where we will have to focus. We are now working on establishing guidelines to improve the care at these points.

COMMENTARY

"*Errare humanum est, perseverare autem diabolicum*" —Lucius Annaeus Seneca, 4 BC to 45 AD

Marc R. de Leval, MD, FRCS

Medical outcomes result from complex interactions among 3 sets of variables: those related to the diseases, those related to the treatments, and those related to the care providers. The majority of outcome researchers have concentrated on illness-specific or procedural-related variables. By and large, human factors related to the performance of care providers have not been included in those analyses. Yet investment in human factors has been shown to improve safety and enhance reliability in high-technology industries in general and aviation in particular.

High-technology medicine such as cardiac surgery shares many properties with what is often referred to as complex social technical systems in which performance depends on complex individual technical and organizational factors and their interactions.[1]

In this issue of the *Journal*, Jacques and colleagues[2] investigate the impact of human errors on team performance and outcomes of staged palliation of hypoplastic left heart syndromes and physiologic equivalents. Repairs of hypoplastic left heart syndromes are models of high-technology surgery par excellence. They have a low error tolerance requiring a sophisticated organizational structure, the coordinated efforts of multiple individuals working in teams, and high levels of cognitive and technical performance.

The authors review the course summaries of 191 patients undergoing operations in a single institution over a 10-year period. Technical and judgment errors at each stage of the Norwood strategy were extracted from these summaries. Human errors affected approximately 50% of the patients at both stage I and II of the Norwood strategy. At stage I, most intraoperative judgment errors are not detected at the time of the operation. Serious technical errors are recognized and addressed intraoperatively (30% of patients at stage I underwent a revision of the repair). Those revisions were not associated with an increased risk of strategy failure (death or transplantation), but they delayed the postoperative recovery. Judgment errors led to an increase in postoperative errors.

Postoperative errors are the strongest and most reliable determinants of poor outcomes. The predictors of postoperative errors are the complexity of the morphologic substrate (more complex patients have a higher risk for error in their management), and errors in intraoperative surgical judgment increase the risk of postoperative errors. The majority of postoperative errors after stage I are foreseeable.

Intraoperative errors at stage II did not compromise outcomes, but despite their low incidence the postoperative errors did have an impact on outcomes.

This study conveys important messages. In the current state of the art, the treatment of complex congenital cardiac

From the Harley Street Clinic, Congenital Heart Centre, London, United Kingdom.
Disclosures: Author has nothing to disclose with regard to commercial support.
Received for publication Feb 7, 2013; accepted for publication March 14, 2013; available ahead of print April 15, 2013.
Address for reprints: Marc R. de Leval, MD, FRCS, the Harley Street Clinic, Congenital Heart Centre, 84 Harley St, 2nd Floor, London W1G 7HW, United Kingdom (E-mail: marc.deleval@hcahealthcare.co.uk).
J Thorac Cardiovasc Surg 2013;145:1475-6
0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2013.03.010

defects, such as hypoplastic left heart syndromes, is prone to errors. Error management should be part of the surgical training. The aviation industry has introduced Crew Resource Management training, which is based on anticipation, detection, and recovery. Previous experience and accurate preoperative investigations should help to anticipate errors. The routine intraoperative echocardiographic control of stage I repair, which led to a revision in 30% of the patients without being associated with strategy failure, is a good illustration of detection and recovery. The surgical team should be mentally and technically prepared to take down a complex repair and to revise it. It is probably the most difficult task for surgeons in training to master. It implies resilience and spare capacity, which can be difficult to acquire. The aviation industry has again introduced the NOTECHS scoring system to analyze effective team performance. The nontechnical skills describe the cognitive or mental skills (decision making, planning, and situation awareness) and interpersonal abilities (team work, communication, and leadership). Those behavioral markers are unlikely to be captured in a retrospective review of clinical summaries. They should be part of a prospective observational study, ideally undertaken by human factors experts. Video camera recordings can be a useful adjunct to the observer's report. The NOTECHS scoring system, currently operational in the airline industry, has been proposed as a method to reduce surgical errors.[3,4]

The interpretation of the strong impact of postoperative errors on outcomes is complex. The sickest infants and those who experienced intraoperative errors clearly are at higher risk of strategy failure. In complex systems, errors are known to escalate in cascade. Intensive care units are complex environments prone to NOTECHS errors. It is not infrequent to have leadership issues with gaps between authority and knowledge. Multiple teams and hierarchies are involved in the management of the same patients. Those at the front line may not have the seniority to pick up trends and insidious changes, which can be premonitory signs of a more serious deterioration (lack of situation awareness). Communication issues are of major importance, with multiple handovers between different teams and between individuals of the same team. Those handovers have multiplied in recent years with the regulation of working hours for the medical profession. The handover of sick infants after heart surgery from the operating room to the intensive care unit has been likened to the pit-stop in Formula I car racing, in which errors are detected by expert observers and video cameras.[5] The authors of this article wisely highlight the importance of hinge points of which handovers are only one example. The generalization of checklists has been a positive step forward to reduce the error rate in these transitions.[6]

References

1. Reason JT. Human Error. Cambridge: Cambridge University Press; 1990.
2. Jacques F, Anand V, Hickey EJ, Kotani Y, Yadava M, Alghamdi A, et al. Medical errors: The performance gap in hypoplastic left heart syndrome and physiologic equivalents? *J Thorac Cardiovasc Surg*. February 20, 2013 [Epub ahead of print].
3. Helmreich RL. On error management: lessons from aviation. *BMJ*. 2000;320: 781-5.
4. Helmreich RL, Merritt AC. Culture at work in aviation and medicine, 1998 Ashgate.
5. Catchpole KR, de Leval M, McEwan A, Pigott N, Elliott MJ, McQuillan A, et al. Patient handover from surgery to intensive care: using Formula 1 pit-stop and aviation models to improve safety and quality. *Paediatr Anaesth*. 2007;17:470-8.
6. de Vries EN, Prins HA, Crolla RM, den Outer AJ, van Andel G, van Helden SH, et al. Effect of a comprehensive surgical safety system on patients outcomes. *N Engl J Med*. 2010;363:1928-37.