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Patient handover from surgery to intensive care: using Formula 1 pit-stop and aviation models to improve safety and quality

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Summary

Background: We aimed to improve the quality and safety of handover of patients from surgery to intensive care using the analogy of a Formula 1 pit stop and expertise from aviation.

Methods: A prospective intervention study measured the change in performance before and after the implementation of a new handover protocol that was developed through detailed discussions with a Formula 1 racing team and aviation training captains. Fifty (23 before and 27 after) postsurgery patient handovers were observed. Technical errors and information omissions were measured using checklists, and teamwork was scored using a Likert scale. Duration of the handover was also measured.

Results: The mean number of technical errors was reduced from 5.42 (95% CI ±1.24) to 3.15 (95% CI ±0.71), the mean number of information handover omissions was reduced from 2.09 (95% CI ±1.14) to 1.07 (95% CI ±0.55), and duration of handover was reduced from 10.8 min (95% CI ±1.6) to 9.4 min (95% CI ±1.29). Nine out of twenty-three (39%) precondition patients had more than one error in both technical and information handover prior to the new protocol, compared with three out of twnety-seven (11.5%) with the new handover. Regression analysis showed that the number of technical errors were significantly reduced with the new handover ($t = -3.63$, $P < 0.001$), and an interaction suggested that teamwork ($t = 3.04$, $P = 0.004$) had a different effect with the new handover protocol.

Conclusions: The introduction of the new handover protocol lead to improvements in all aspects of the handover. Expertise from other industries can be extrapolated to improve patient safety, and in particular, areas of medicine involving the handover of patients or information.

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Introduction

The handover of infants after complex congenital heart surgery from the theater team, who have intimate knowledge of the patient, to the intensive care team has been found to be an important period in the recovery and outcome of these vulnerable patients (1). During this period, all the technology and support (ventilation, 2-4 monitoring lines, multiple inotropes and vasodilators) is transferred twice, from theater systems to portable equipment, then to the intensive care systems, within 15 min. At the same time, knowledge of the patient gained by the surgical team in the 4- to 8-h procedure is handed over to the intensive care unit (ICU). It is the combination of tasks that make this process susceptible to error (2), at a time when the patient is most vulnerable. To improve safety and quality of care we sought help from experts in two high-reliability industries.

The pit-stop in Formula 1 motor racing was seen as a model example of how a multi-professional team comes together as single unit to effectively perform a complex task (change four tyres and fill with fuel) under huge time pressure (approx 7 s) with minimal error (Figure 1). This was targeted as an industry with analogies to the handover of patients from theater to ICU where multiprofessional specialists (surgeons, anesthetist and ICU staff) reconfigure, as a single unit under time pressure, to safely transfer all equipment and information. The requirement for teamwork and safety skills also suggested an analogue with the aviation industry, which has a 20-year history of effectively training in these abilities (3) and is now being successfully employed in health care (4).

The aim of this study was to combine this expertise with our own knowledge to develop a simple, reliable, easily trainable handover protocol to improve the safety and quality of patient handover in this short but critical period after complex congenital heart surgery.

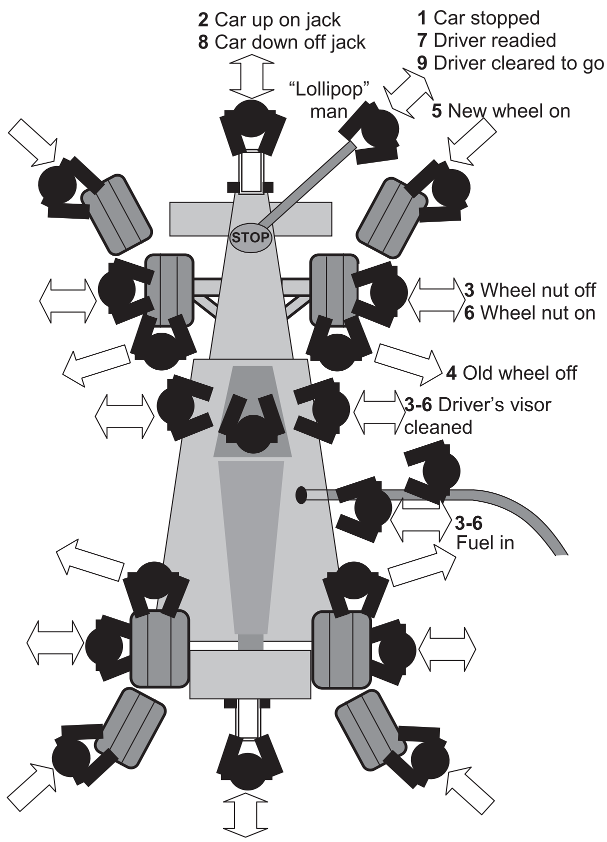


Figure 1
A Formula 1 pit-stop.

Methods

Study design

This was a prospective intervention with direct observation assessment of handover performance conducted in the cardiac ICU of a tertiary treatment center for congenital heart surgery treating approximately 500 pediatric cardiac cases per annum. Ethical approval was granted by the Local Research Ethics Committee. Staff rotation meant that it was not possible to randomize teams to treatment and nontreatment groups.

Development of the handover protocol

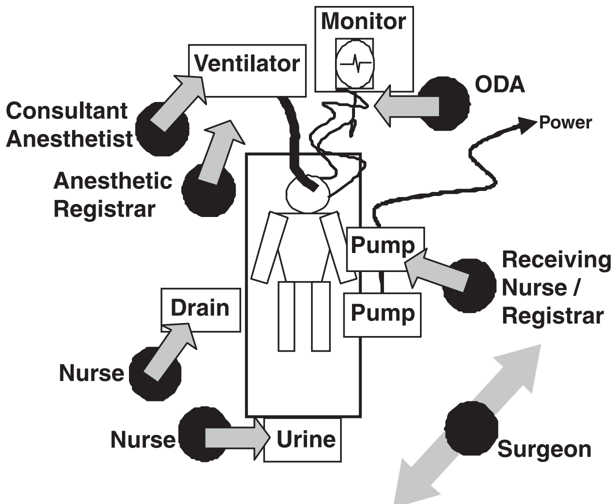
Members of the research team were invited by a Formula 1 Racing team (Ferrari F1) to watch practice pit-stops and to visit the team headquarters (Maranello). Detailed discussions were conducted with the race director during this single visit. Safety themes and analogues with healthcare were established, and new practices were identified through subsequent discussions with anesthetists, surgeons, intensivists and nurses. Two aviation training captains were able to observe several handovers, and suggest further improvements. The lessons learned for developing handover protocols from Formula 1 and aviation are

Table 1
Lessons learned from Formula 1 motor racing and aviation industries for improving patient handover from surgery to intensive care

Safety theme	*Practice*	*Establishment of handover protocol*
Leadership	Formula 1: the 'lollipop' man coordinates the pit-stop. Aviation: the captain has command and responsibility	Old: unclear who was in charge. New: the anesthetist was given overall responsibility for coordinating the team, which was transferred to the intensivist at the end of the handover
Task sequence	Formula 1 and aviation: there is a clear rhythm and order to events	Old: inconsistent and nonsequential. New: three phases defined: 1. Equipment and technology handover; 2. Information handover; 3. Discussion and plan
Task allocation	Formula 1: each team member has only one or two clearly defined tasks. Aviation: explicit acknowledged allocation of tasks for emergencies	Old: informal and erratic. New: people allocated tasks: ventilation – anesthetist; monitoring – ODA; drains – nurses. The anesthetist identified and handed information over to the key receiving people
Predicting and planning	Formula 1: failure modes and effects analysis (FMEA) used to breakdown pit-stops into individual tasks and risks. Aviation: pilots are trained to anticipate the expected, and to plan contingencies	Old: risks identified informally and often not acted upon. New: a modified FMEA was conducted and senior representatives commented on highest areas of risk. Safety checks were introduced, and the need for a ventilation transfer sheet was identified
Discipline and composure	Formula 1: very little verbal communication during a pit stop. Aviation: explicit communication strategies used to ensure a calm and organized atmosphere	Old: ad hoc and unstructured, with several simultaneous discussions in different areas of the ICU and theaters. New: communication limited to the essential during equipment handover. During information handover the anesthetist, then the surgeon, speak alone and uninterrupted, followed by discussion and agreement of the recovery plan
Checklists	Formula 1 and aviation: a well-established culture of using checklists	Old: none. New: a checklist was defined and used as the admission note by the receiving team
Involvement	Aviation: crew members of all levels are encouraged and trained to speak up	Old: communications primarily within levels (e.g., consultant to consultant or junior to junior). New: all team members and grades encouraged to speak up. Built into discussions in phase 3
Briefing	Formula 1 and aviation: well-established cultures of briefing even on race day, and before every flight	Old and new: a process was already in place, where planning begins in a regular multidisciplinary meeting, and is reconfirmed the week before surgery, with further problems highlighted on the day
Situation awareness	Formula 1: The 'lollipop man' has overall situation awareness at pit-stops. Aviation: pilots are trained for situation awareness. In difficult circumstances the senior pilot manages the wider aspects of the flight while the other pilot controls the aircraft	Old: not previously identified as being important. New: the consultant anesthetist and intensivist have responsibility for situation awareness at handover, and regularly stand back to make safety checks
Training	Formula 1: a fanatical approach to training and repetition of the pit-stop. Aviation: training and assessment are regularly conducted in high-fidelity simulators	Old: no training existed. New: a high turnover of staff requires an alternative approach. The protocol could be learnt in 30 min. Formal training was introduced, and laminated training sheets detailing the process are provided at each bedside
Review meetings	Formula 1: regular team meetings to review events. Aviation: crew are encouraged to debrief after every flight	Old and New: a weekly clinical governance meeting, attended 50+ people, was already in place where problems and solutions could be openly discussed

Table 2
Summary of the new handover protocol

Phase 0: prehandover	The Patient Transfer Form is completed by the anesthetist and collected from theater at least 30 min before the patient is transferred to the ICU.
	The receiving nurse ensures the bed space is set up according to the monitoring, ventilation and other requirements specified on the Patient Transfer Form.
	The receiving doctor ensures that all appropriate paperwork is ready.
Phase 1: equipment and technology handover	On arrival the team transfers the patient ventilation, monitoring and support from portable systems used during the transfer to the ICU systems.



	Safety check: the anesthetist checks the equipment and that the patient is appropriately ventilated and monitored and is stable. The receiving nurse and doctor are identified and confirm their readiness.
Phase 2: information handover	The anesthetist, then the surgeon, speak alone and uninterrupted, providing the relevant information about the case, using the *Information Transfer Aid Memoir*.
	Safety check: the receiving nurse and doctor should use the *Information Transfer Aid Memoir* to check that all necessary information has been obtained, and ask appropriate questions.
Phase 3: discussion and plan	The surgeon, anesthetist and receiving team discuss the case as a group. The receiving physician manages the discussions, identifies anticipated problems, and anticipated recovery is discussed.
	The ICU team now has responsibility for patient care, and confirms the plans for the patient.

described in Table 1 and the new handover protocol and process which emerged are summarized in Table 2.

Patient population

A total of 50 patient handovers were studied, with 23 before the introduction of the new handover, and 27 following the new protocol. Though patients themselves were not the focus of the study, they were selected in order to achieve a representative range of cases and risks, balanced between pre- and post-study conditions. They ranged in age from 2 days to 16 years, all were intubated and mechanically ventilated, required one or more intravenous infusions and had one or more invasive pressure monitoring lines, catheters and drains. They had just undergone open heart surgery to correct congenital heart defects, and had been in the operating theater for 2–6 h. The RACHS-1 method (5) was utilized to class patients into risk groups, with level 1 and 2 operations designated as low risk, and levels 3 and 4 designated as high risk. In the old handover group 15 were in the low-risk surgery group, and eight were in the high-risk surgery group, with 17 in the low-risk group and 10 in the high-risk group after introduction of the new handover protocol.

Evaluation

A single observer (KC), experienced in the observation of human error in surgical settings, was present for all handovers studied. Performance was assessed on four separate dimensions. First, an error capture

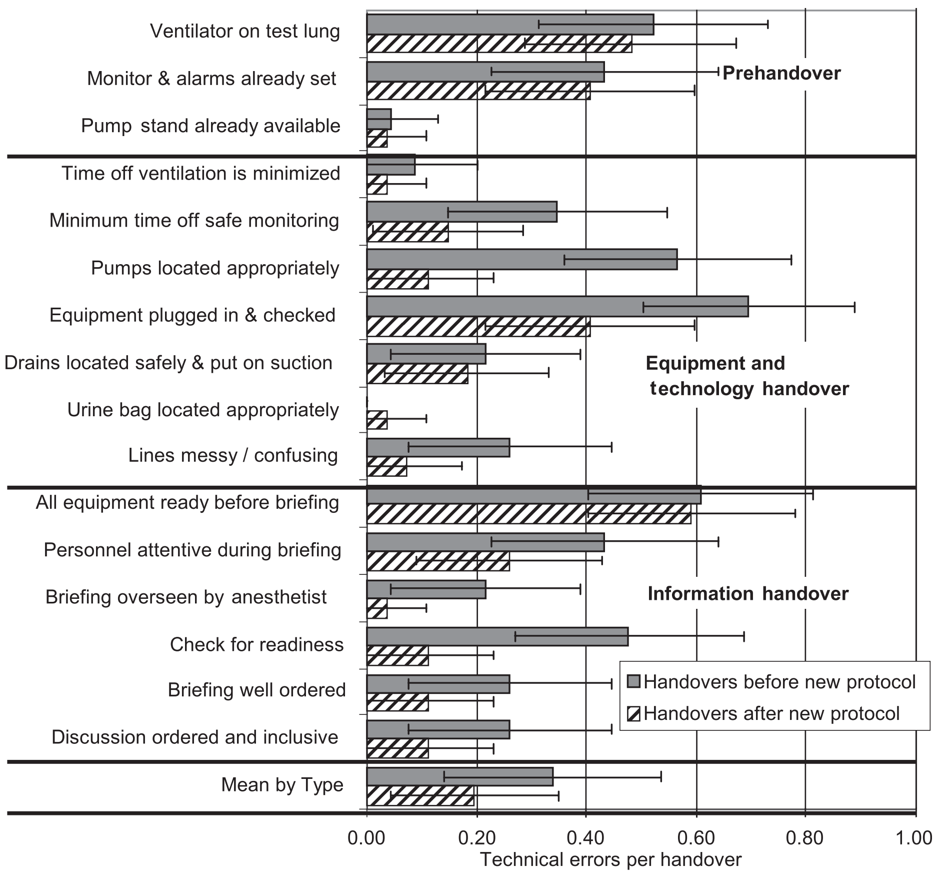


Figure 2
Technical errors per handover before and after the new protocol, with 95% confidence intervals.

checklist consisting of 16 items (Figure 2) was used to observe technical errors during the three basic stages in the handover process in the ICU, both before and after the introduction of the new handover protocol. An error was recorded for each item that was performed incorrectly or with unusual difficulty. Secondly, the quality of handover information was assessed using a checklist consisting of 17 items (Figure 3). An omission was recorded if that piece of information was not mentioned in the handover briefing or subsequent discussion. These first two measurement methods were based on recognized areas of weakness which had been previously identified through failure modes and effects analysis. Thirdly, overall duration of the handover was recorded, from the moment the patient entered ICU to the moment the theater team left the bedside. Finally, as teamwork is a fundamental component of the handover process, team performance was measured as a covariate of handover performance by assigning a score to each handover using a 5-point Likert scale on four dimensions, as shown in Table 3. Scale development was based on our previous collaborations with pilots in surgery (6), and was then configured specifically for the assessment of patient handover. In order not to bias the measures toward the new processes, all measures were developed, tested with five prestudy handovers, and deployed in the preintervention phase prior to deciding upon the detail of the new handover.

Results

The mean number of technical errors per handover (Figure 2) fell after the new handover protocol from 5.42 (95% CI ±1.24) to 3.15 (95% CI ±0.71). Following the new handover protocol, the mean number of information handover omissions (Figure 3) was reduced from 2.09 (95% CI ±1.14) to 1.07 (95% CI

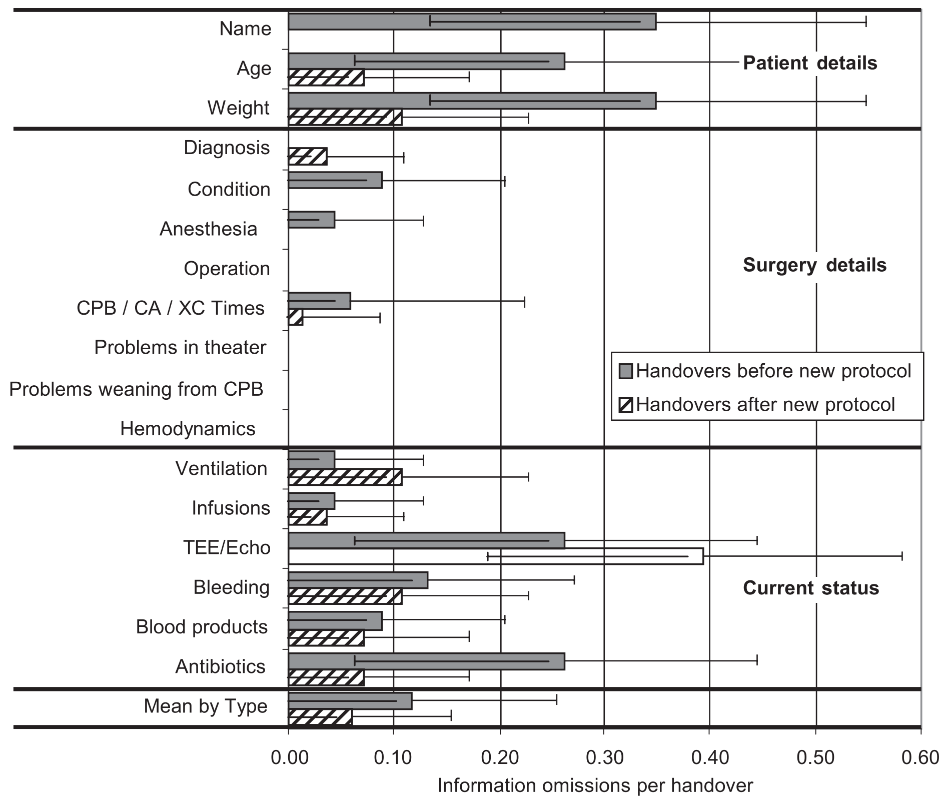


Figure 3
Information omissions per handover before and after the new protocol, with 95% confidence intervals.

±0.55). Nine out of twenty-three (39%) precondition patients had more than one error in both technical and information handover, compared with three out of twenty-seven (11.5%) in the new handover group. Of these patients, three (13%) experienced five or more errors in both technical and information handover prior to the new handover process, compared with only one (3%) in the postgroup. This is reflected in the two-tailed Pearson's product-moment correlation between technical errors and information omission, which was found to be significant with the old handover ($r = 0.513$, $P < 0.01$, $n = 23$), but not with the new handover ($r = 0.262$, $P = 0.186$, $n = 27$). Thus, a poor technical handover was more likely to be compound by the omission of information in the briefing, before the introduction of the new handover, than following the new handover. Mean duration of handover was reduced from 10.8 min (95% CI ±1.6) to 9.4 min (95% CI ±1.29), and although this is a nonsignificant difference, the change is in the same direction as all other measures.

Multiple linear regressions were conducted to examine the effect of operative risk, team performance and study phase on the number of technical errors, information omissions, and duration of the process (Table 4). The pre- and post-new protocol regression functions for the errors are shown in Figure 4, illustrating the importance of effective teamwork in the reduction of errors. The reduction in gradient of the relationship between team performance and error suggests that where teamwork was judged to be less effective, errors with the new handover protocol were less frequent than with the old handover process.

Discussion

We have demonstrated that it is possible to utilize expertise from the Formula 1 and aviation industries to improve performance. Whilst this is a small pilot study in a specialized area of medicine, the data are encouraging as they show the effectiveness of a simple and easily trainable protocol at the interface

Table 3
Team performance measurement scale

Leadership & teamwork				
Good: good coordination; good communication; mutually supportive; assertive, calm, encouraging leadership Bad: poor coordination; poor communication; unsupportive; nonvocal, aggressive, unassertive leadership				
Very bad				Very good
1	2	3	4	5
Task management				
Good: plans made prior to actions; good task prioritization; maintenance of standards; using resources; the right things happening at the righttime Bad: actions made without plans; poor coordination; poor task prioritization; poor standards; resources incorrectly or inappropriately used; delays				
Very bad				Very good
1	2	3	4	5
Workspace and equipment				
Good: appropriate equipment not immediately available; correct operation of equipment; good alarm resolution; functionality and serviceability checked Bad: equipment not immediately available; poor operation of equipment; poor or slow alarm resolution; equipment not checked				
Very bad				Very good
1	2	3	4	5
Situation awareness				
Good: monitors visible; monitoring reliable; monitoring information gathered; pump displays visible; pump information gathered; recognition of patient state; anticipation of patient state Bad: monitors not visible; monitoring unreliable; monitoring information not gathered; pump displays not visible; pump information not gathered; poor recognition of patient state; poor anticipation of patient state				
Very bad				Very good
1	2	3	4	5

Table 4
Multiple linear regression coefficients for the main performance measures

Performance measure		*Constant*	*New protocol*	*RACHS levels 3–6*	*Teamwork*	*New protocol × teamwork*	r^2
Technical errors	Gradient	18.72	−9.96	0.47	−1.17	0.700	63.4%
	t	8.23	−3.63	0.974	−6.05	3.04	
	P	<0.001	0.001	0.335	0.001	0.004	
Information omissions	Gradient	7.95	−5.10	1.41	−0.552	0.366	31.3%
	t	3.14	−1.67	2.63	−2.57	1.43	
	P	0.003	0.102	0.012	0.014	0.160	
Duration of handover	Gradient	13.80	−5.42	1.09	0.311	0.350	10.8%
	t	2.89	−0.939	1.56	−0.77	0.72	
	P	0.006	0.353	0.126	0.447	0.473	

between theater and intensive care teams. These results may also inform other areas of medicine where handovers are conducted frequently, under time pressure and with limited opportunities for training.

The new handover protocol focused on leadership, task allocation, rhythm, standardized processes, checklists, awareness, anticipation, and communication. It was simple to understand, was easily trainable, and could be established within 15–30 min at staff induction. Following introduction of the handover, improvements were found across almost the entire process. With mortality rates of 2–3%, the size of the study is too small to examine patient outcome, but it is nonetheless important that the likelihood of multiple errors with individual patients was reduced, as the avoidance of compounding errors is a fundamentally important component of safety (2,7,8), and has been shown in other studies to affect outcome (1,9,10). It also

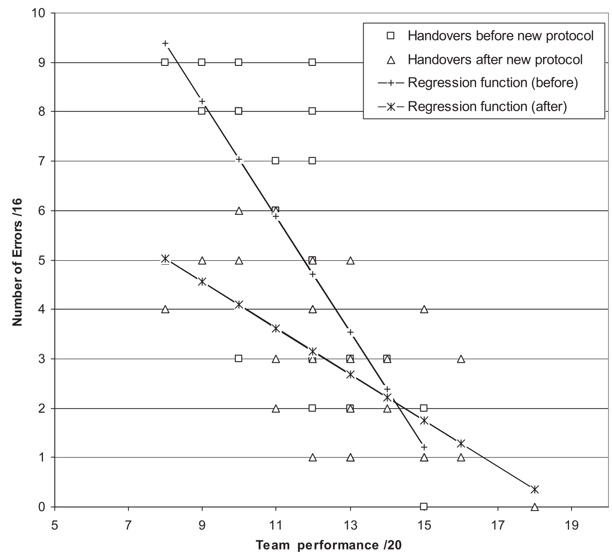


Figure 4
Errors and team performance with regression functions before and after introduction of the new handover protocol.

appeared that the new handover changed the impact of teamwork on the process, reducing the need for good team performance to mitigate against large numbers of errors, but emphasizing the value of teamwork in achieving the lowest rates of error. However, given that the teams studied may have been highly effective already, this conclusion would need to be examined with teams of more widely varying composition and ability. It was encouraging that, as these teams are often under pressure to return to the operating theater as soon as possible, to accomplish these improvements the new handover took no longer than before.

Whilst it is encouraging that analogies from other industries with longstanding cultures of safety and reliability may be extrapolated, it is also important to recognize the unique demands of health care. One crucial difference that emerged was that Formula 1 and aviation both have a relatively stable workforce, with minimal staff turnover. For example, out of about 20 members of a pit team, only one or two members change annually. In contrast, turnover of staff in health care is far higher, with six residents rotating every 3 months in the study unit, and a nurse turnover of approximately 10%. This meant it was vital to introduce a process that could be easily understood and trained in a timely fashion. It was therefore particularly encouraging that we were able to successfully establish the new protocol and achieve an acceptable level of compliance (for example, approximately 95% of the patient transfer forms were completed and sent to ICU at the appropriate time) with less than 30 min of training.

With an increasing reliance on shift work, and limited time available for training (11), team interfaces are known to be an area of potential weakness (12–18). These preliminary results suggest that further research is warranted to examine the sustainability of the protocol, the accuracy of the measurements (19), and whether the present model might be successfully extrapolated to sustain quality and safety in other team handovers.

Conclusions

The development of a simple, easily trainable handover process using expertise from other high-risk industries reduced errors and improved information transfer with no penalty in handover duration and negligible training overhead. We believe this work may be extrapolated to handovers in other areas of medicine, and would encourage further attempts to systematically evaluate this protocol and to combine expertise from other industries with that of health care.

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References

1 de Leval MR, Carthey J, Wright DJ *et al.* Human factors and cardiac surgery: a multicenter study. *J Thorac Cardiovasc Surg* 2000; **119:** 661–672.

2 Woods D, Patterson E. How unexpected events produce an escalation of cognitive and coordinative demands. In: Hancock PA, Desmond PA, eds. *Stress Workload and Fatigue*. Hillsdale, NJ: Lawrence Erlbaum, 2004: 290–304.
3 Fletcher GCL, McGeorge P, Flin RH *et al.* The role of non-technical skills in anaesthesia: a review of current literature. *Br J Anaesth* 2002; **88:** 418–429.
4 Morey JC, Simon R, Jay GD *et al.* Error reduction and performance improvement in the emergency department through formal teamwork training: evaluation results of the MedTeams project. *Health Serv Res* 2002; **37:** 1553–1581.
5 Jenkins KJ, Gauvreau K, Newburger JW *et al.* Consensus-based method for risk adjustment for surgery for congenital heart disease. *J Thorac Cardiovasc Surg* 2002; **123:** 110–118.
6 Catchpole K, Godden PJ, Giddings AEB *et al.* Identifying and reducing errors in the operating theatre. PS012. Patient Safety Research Programme. 2005. http://pcpoh.bham.ac.uk/publichealth/psrp/Publication_PS012.htm [accessed on 20 November 2006].
7 Reason J. *Managing the Risks of Organisational Accidents.* Aldershot: Ashgate, 1997.
8 Catchpole KR, Giddings AE, de Leval MR *et al.* Identification of systems failures in successful paediatric cardiac surgery. *Ergonomics* 2006; **49:** 567–588.
9 Hofer TP, Hayward RA. Are bad outcomes from questionable clinical decisions preventable medical errors? A case of cascade iatrogenesis. *Ann Intern Med* 2002; **137:** 327–333.
10 Woolf SH, Kuzel AJ, Dovey SM *et al.* A string of mistakes: the importance of cascade analysis in describing, counting, and preventing medical errors. *Ann Fam Med* 2004; **2:** 317–326.
11 Jones GJ, Vanderpump MP, Easton M *et al.* Achieving compliance with the European Working Time Directive in a large teaching hospital: a strategic approach. *Clin Med* 2004; **4:** 427–430.
12 Chan LS, Schonfeld N. How much information is lost during processing? A case study of pediatric emergency department records. *Comput Biomed Res* 1993; **26:** 582–591.
13 Kluger MT, Bullock MF. Recovery room incidents: a review of 419 reports from the Anaesthetic Incident Monitoring Study (AIMS). *Anaesthesia* 2002; **57:** 1060–1066.
14 Kostopoulou O, Shepherd A. Fragmentation of treatment and the potential for human error in neonatal intensive care. *Top Health Inf Manage* 2000; **20:** 78–92.
15 Horn J, Bell MD, Moss E. Handover of responsibility for the anaesthetised patient – opinion and practice. *Anaesthesia* 2004; **59:** 658–663.
16 O'Connell B, Penney W. Challenging the handover ritual. Recommendations for research and practice.. *Collegian* 2001; **8:** 14–18.
17 Pothier D, Monteiro P, Mooktiar M *et al.* Pilot study to show the loss of important data in nursing handover. *Br J Nurs* 2005; **14:** 1090–1093.
18 Castledine G. The importance of a good shift handover of patients. *Br J Nurs* 2006; **15:** 524.
19 Carthey J. The role of structured observational research in health care. *Qual Saf Health Care* 2003; **12:** 13ii–16ii.

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