

# Improving patient safety by identifying latent failures in successful operations

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**Background.** The risk of technical failure during operations is recognized, but there is evidence that further improvements in safety depend on systems factors, in particular, effective team skills. The hypotheses that small problems can escalate to more serious situations and that effective teamwork can prevent the development of serious situations, were examined to develop a method to assess these skills and to provide evidence for improvements in training and systems.

**Method(s):** Observations were made during 24 pediatric cardiac and 18 orthopedic operations. Operations were classified by accepted indicators of risk and the observations used to generate indicators of performance. Negative events were recorded and organized into 3 levels of clinical importance (minor problems, those negative events that were seemingly innocuous; intraoperative performance, the proportion of key operating tasks that were disrupted; and major problems, events that compromised directly the safety of the patient or the quality of the treatment). The ability of the team to work together safely was classified using a validated scale adapted from research in aviation. Operative duration was also recorded.

**Result(s).** Both escalation and teamwork hypotheses were supported. Multiple linear regression suggests that for every 3 minor problems above the 9.9 expected per operation ( $P < .001$ ), intraoperative performance reduces by 1% ( $P = .005$ ), and operative duration increases by 10 minutes ( $P = .032$ ). Effective teams have fewer minor problems per operation ( $P = .035$ ) and consequently higher intraoperative performance and shorter operating times. Operative risk affected intraoperative performance ( $P = .004$ ) and duration ( $P < .001$ ), with the type of operation affecting only duration ( $P < .001$ ). Eight major problems were observed; these showed a strong association with risk, intraoperative performance, teamwork, and the number of minor problems.

**Conclusion(s).** Structured observation of effective teamwork in the operating room can identify substantive deficiencies in the system, even in otherwise successful operations. Decreasing the number of minor problems can lead to a smoother, safer, and shorter operation. Effective teamwork can help decrease the number of small problems and prevent them from escalating to more serious situations. The most effective and sustainable route to improved safety is in capturing these minor problems and identifying related system improvements, combined with training in safe team working. This method is a validated and practical way to improve performance during otherwise successful operations. (Surgery 2007;142:102-10.)

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THE PERFORMANCE OF HIGHLY TRAINED PROFESSIONALS is known to be variable and subject to unavoidable human error. Prevention of unintended injury in healthcare depends on identifying and improving the components of the system<sup>1</sup>

rather than a 'blaming and training' approach to individuals. This 'systems approach' acknowledges that deficiencies exist at many sites in the process and that these deficiencies may be activated by human errors with potentially serious consequences.<sup>2</sup> The

prospective identification of such components in an otherwise successful system can lead to removal of these error-inducing conditions before they can contribute to patient injury. Such a systems-based approach is likely to provide greater and more sustained benefit than by paying yet more attention to obvious, but often irreversible, human errors.

Better understanding is needed, because injuries of major significance can result from the escalation of a series of apparently minor problems.<sup>3-7</sup> By observing all negative events at 3 levels of severity, we aimed to show that the inherent risk and complexity of operative procedures,<sup>8,9</sup> interacting with the interplay of individuals working together,<sup>10-12</sup> can alter safety and outcome. The application of the same technique in 2 contrasting operating room environments suggests a general method for improvement that may be applied to operating room conditions in both real and simulated operations, as is already the practice in aviation.

## MATERIALS AND METHODS

This was a prospective, observational study of intraoperative events in 2 different types of intraoperative care. Pediatric cardiac operation features multiple specialties, close coupling of concurrent tasks, uncertainty, changing plans, and a high workload,<sup>13</sup> and was chosen as a model of complex operation.<sup>3</sup> Elective orthopedic operation was investigated in another hospital in which the orthopedic operations were high volume, low risk,<sup>14</sup> highly proceduralized, and a relatively invariant type of operative treatment. Two hospitals, one a specialist children's hospital, and the other a general hospital, were used to show findings that would be applicable across a broad range of operative environments. The same observer was used at both hospitals to ensure methodologic consistency.

Ethics approval was granted locally at both hospitals, and consent was given by patients and staff involved. A single observer was present during each operation and collected data both through pre-specified checklists and free-hand notes.<sup>15</sup> The observer was a human factors practitioner (KC) with 5 years of post-doctoral experience in observational methods<sup>16</sup> and measurement of human performance,<sup>17</sup> but with little prior healthcare experience. He spent 6 months preparing at the research hospitals by talking to practitioners, attending multi-disciplinary meetings, studying textbook descriptions of the operations, and by observing 38 pediatric and 10 orthopedic operations before data collection. Members of the teams changed, but to further ensure that these preliminary observations

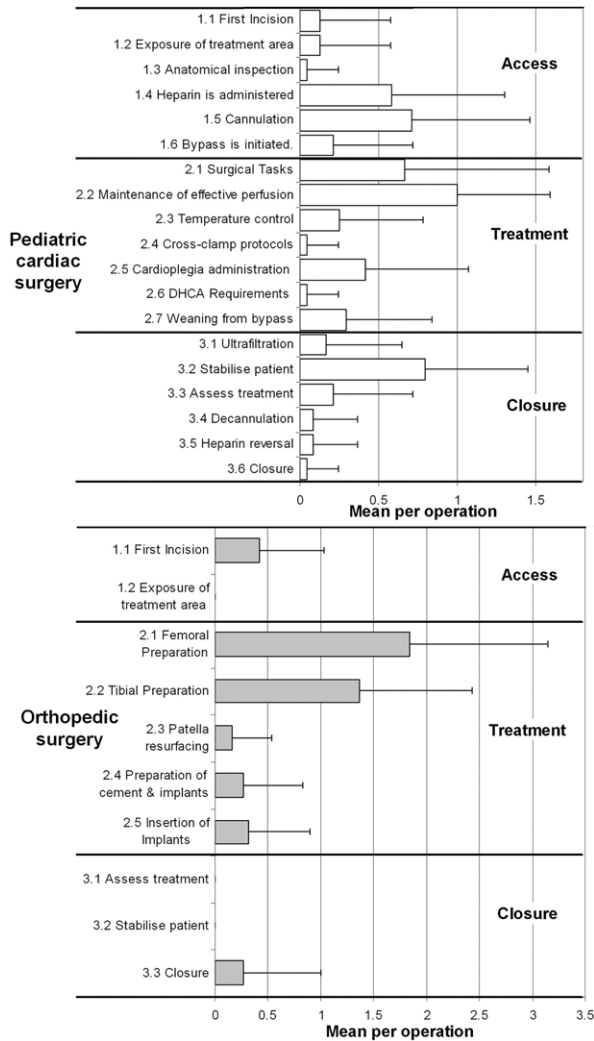
LEADERSHIP & MANAGEMENT			
<b>Leadership</b>	Involves / Reflects on suggestions / Visible / Accessible / Inspires / Motivates / coaches		
<b>Maintenance of standards</b>	Subscribes to standards / Monitors compliance to standards / Intervenes if deviation / Deviates with team approval / Demonstrates desire to achieve high standards		
<b>Planning &amp; preparation</b>	Team participation in planning / Plan is shared / Understanding confirmed / projects / changes in consultation		
<b>Workload management</b>	Distributes tasks / monitors / reviews / prioritises tasks / Allots adequate time / responds to stress		
<b>Authority &amp; assertiveness</b>	Advocates position / Values team input / Takes control / Persistent / Appropriate assertiveness		
TEAMWORK & CO-OPERATION			
<b>Team building/maintaining</b>	Relaxed / Supportive / Open / Inclusive / Polite / Friendly / Use of humour / Does not compete		
<b>Support of others</b>	Helps others / Offers assistance / gives feedback		
<b>Understanding team needs</b>	Listens to others / Recognises abilities of team / Condition of others considered / Gives personal feedback		
<b>Conflict solving</b>	Keeps calm in conflicts / Suggests conflict solutions / Concentrates on what is right		
PROBLEM SOLVING & DECISION MAKING			
<b>Definition &amp; Diagnosis</b>	Uses all resources / Analytical decision making / Reviews factors with team		
<b>Option Generation</b>	Suggests options / Asks for options / Reviews outcomes / Confirms opinions		
<b>Risk Assessment</b>	Estimates risks / Considers risk in terms of team capabilities / Estimates outcome		
<b>Outcome Review</b>	Reviews outcomes / Reviews new options / Objective, constructive and timely reviews / Makes time for review / Seeks feedback from others / Conducts post treatment review		
SITUATION AWARENESS			
<b>Notice</b>	Considers all elements / Monitors vital signs & progress of operation / Asks for or shares information / Encourages vigilance / Checks and reports changes / Requests reports and updates		
<b>Understand</b>	Cross-checks above / Shares mental models / Speaks up when unsure / Updates other team members		
<b>Think Ahead</b>	Identifies future problems / Discusses contingencies / Plans for future patient states / Anticipates high workload / Discusses constraints / Uses low workload periods		
Below Standard = 1	Basic Standard = 2	Standard = 3	Exceed = 4
Behaviour directly compromises patient safety and effective teamwork.	Behaviour in other conditions could directly compromise patient safety and effective teamwork.	Behaviour maintains an effective level of patient safety and teamwork.	Behaviour enhances patient safety and teamwork. A model for all other teams.

Figure 1: Surgical NOTECHS measurement framework

Fig 1. Operative NOTECHS measurement framework.

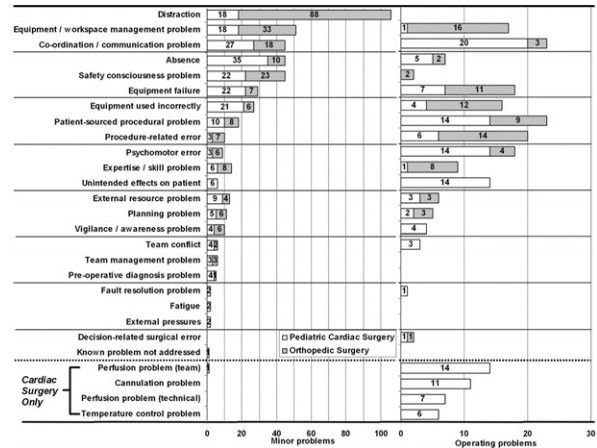
were not biased toward particular surgeons, the observer received further training from 2 retired airline pilots with observational experience in operating rooms (TD and GH). In all operations, a video recording was made of the operating room team from 2 viewpoints; in pediatric cardiac operations the operative field and video output from the anesthetic workstation were also recorded. Each video recording was analyzed postoperatively by the observer to confirm real-time observations. Where further details were required, events were also discussed with key members of the team within 24 hours of the operation. Video observations and discussions were used to ensure the quality of the observations and did not change substantially the original scores, although this was not examined explicitly. Constraints imposed by the ethics committees and the consent process required of staff did limit use of the video recording to the observer alone, and all recordings were destroyed after analysis.

Four observational measurements were taken including negative intraoperative events at 3 levels of severity, and a teamwork classification (Fig 1). Events at the lowest level of severity, described as *minor problems*, were undesirable but did not affect



**Fig 2.** Operating problems in pediatric cardiac operation (*top*) and orthopedic operation (*bottom*), with 95% confidence intervals.

directly the “operative flow.” If one of these problems disrupted a key task, it was considered to be an *operating problem*. These key tasks were defined by the observer and were based on generic text book methods combined with accepted local practices. They included both operative steps (eg, aortic cannulation; transaction of the distal femur), and other key process elements (eg, heparin administration; preparation of bone cement). In pediatrics, there were 97 key tasks organized into 19 top-level processes, whereas in orthopedics, there were 85 key tasks organized into 10 top-level processes (Fig 2). This approach allowed the generation of an *intraoperative performance* score that expressed the operating problems as a proportion of the total number of successfully completed tasks (ie, operating problems subtracted from the total



**Fig 3.** Number and types of minor problems and operating problems observed.

number of key tasks, divided by the total number of key tasks, and expressed as a percentage). To identify comprehensively the causes of the range of problems faced by the operative teams, all minor and operating problems were assigned to one of 27 common categories during the analysis<sup>18,19</sup> (Fig 3). Details of *major problems*, more serious events that compromised directly the safety of the patient or the quality of the treatment, were also recorded and formed the third level of severity. Table I summarizes the range of problems used to assess intraoperative events.

For the classification of effective team performance, an assessment was made based on the NOTECHS scoring system in operational use currently in the airline industry<sup>20,21</sup> and previously adapted successfully to medicine.<sup>22,23</sup> The tool was adapted for use with operative teams after consultation with 2 aviation trainers, 2 cardiac surgeons, 1 vascular surgeon, and 1 orthopedic surgeon. A classification of 1 (Below Standard) to 4 (Exceed), anchored by a generic framework and specific behaviors, was given on each dimension at 3 specified times in each operation. For example, where the surgeon had ignored an appropriate suggestion by another team member, a basic or below standard score was given on the teamwork and cooperation dimension depending on the severity of the situation. Alternatively, where all team members were aware of and discussed the progress of the operation and the state of the patient, a standard or exceed score would be given on the situation awareness dimension depending on the quality of the discussions. For pediatric cardiac operation, the evaluation was made from the video recording of the operation.<sup>24</sup> In this type of operation, 8 or

**Table I.** Measures and examples

Measure	Description	Example	Severity
Minor problems	Events that had a small negative effect on the operation, but did not affect key tasks directly	<b>Cardiac:</b> Circulating nurse absent when needed <b>Orthopedic:</b> Difficulty finding instrument hidden under equipment trays	Seemingly inconsequential
Operating problems	Events that disrupted key intraoperative tasks; used to generate the intraoperative performance score	<b>Cardiac:</b> Perfusion problems as a result of aortic cannula obstruction <b>Orthopedic:</b> Surgeon places cutting block on upside down	Disruptive but not dangerous
Major problems	Events that directly compromised the safety of the patient or the quality of the treatment	<b>Cardiac:</b> Surgeon forgets to close atrial septostomy (Table III) <b>Orthopedic:</b> Misaligned tibial cut leads to sloped plateau	Potentially dangerous

**Table II.** Multiple linear regression coefficients for the main performance measures

Measure		Constant	Orthopedic operation	High risk	Minor problems	Effective teamwork	r <sup>2</sup> (%)
Minor problems	Gradient	9.9	1.6	2.6	N/A	-3.3	25
	<i>t</i>	6.7	1.1	1.5	N/A	-2.2	
	<i>P</i>	<.001	.282	.144	N/A	.035	
Intraoperative performance (%)	Gradient	97.0	-0.7	-2.8	0.3	0.5	52
	<i>t</i>	53.4	-0.9	-30.8	-3.0	0.6	
	<i>P</i>	<.001	.359	.004	.005	.55	
Duration (min)	Gradient	175.3	-110.9	77.6	3.6	-5.5	79
	<i>t</i>	7.5	-7.3	4.3	2.2	-0.3	
	<i>P</i>	<.001	<.001	<.001	.032	.741	

more people were involved in many simultaneous activities that were often too rapid and numerous to capture in real time. In orthopedic operation, the observer made observations in real time. This type of operation involved only 5 people, there was little simultaneous activity, and real-time observation was considered to be comprehensive. This methodologic difference also served to emphasize the broad applicability of this technique. Once data collection was complete, the sample for each operative type was split equally into 2 groups, with those teams achieving a higher number of standard and exceed scores classed as effective, and those teams with a higher number of below standard and basic standard scores classed as ineffective.

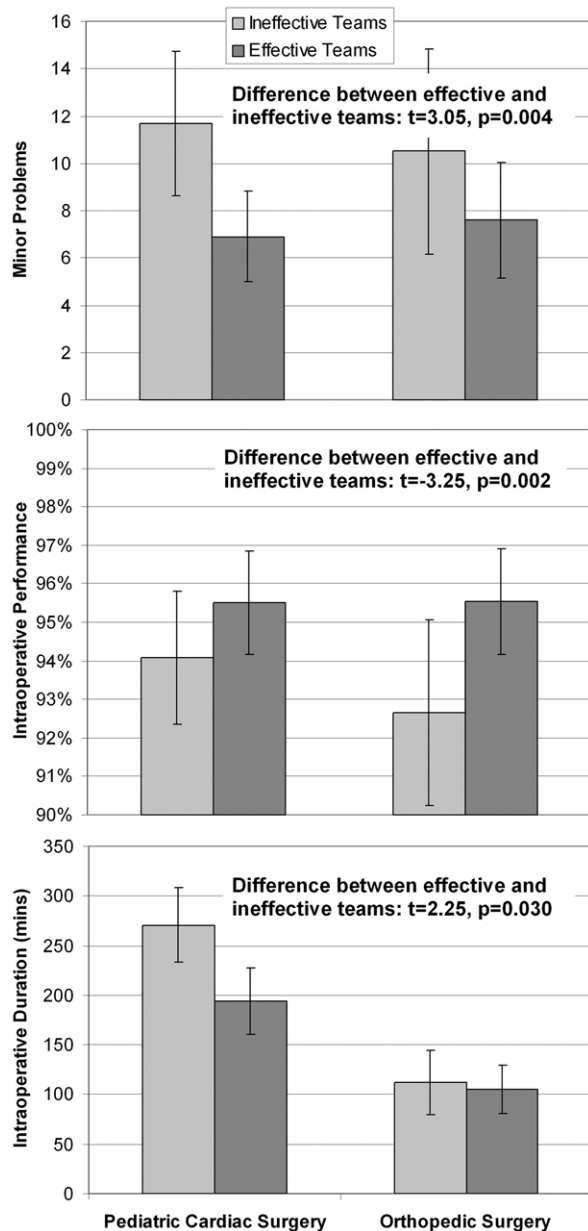
Operations were classified into high risk and low risk using accepted methods. In pediatric cardiac operation, the RACHS-1 system<sup>25</sup> was used, with level 1 and 2 operations (eg, ventricular septal defect closure) designated as low risk, and levels 3, 4, and 6 (eg, arterial switch operations) designated as high risk. In orthopedic operation, primary joint replacement operations were designated as low

risk, whereas revisions of a joint replacement were designated as high risk.<sup>26</sup> Operative duration (first incision to final closing suture) was also recorded as a surrogate measure of outcome.

To examine the escalation and the teamwork hypotheses, the effects on minor problems, intraoperative performance, and operative duration of operative type, risk, and team skills were modeled using 3 linear regressions. Intraoperative performance was used in preference to operating problems, because it provided a clearer expression of the difficulties encountered within an operation relative to the inherent demands of the operation. Due to their relative infrequency, major problems were analyzed for trends using *t* tests.

## RESULTS

Forty-two operations were studied: 24 in pediatrics, and 18 in orthopedics. All operations were regarded as having a successful outcome with no 28-day mortality. None of the operations studied were considered to be unusual in terms of the individuals involved, the procedures themselves, or



**Fig 4.** Influence of teamwork and operative type on minor problems (*top*), intraoperative performance (*middle*), and duration (*bottom*), with 95% confidence intervals.

the condition of the patients. Often, the same members of the operating room team were involved, but neither members nor roles were always identical. In orthopedic operation, the first surgeon was always a consultant or his specialist registrar, and most operations featured the same anesthesiologist. The orthopedic nurses usually came from a pool of 4 individuals who interchanged roles regularly. As no direct effect on patient outcome was experienced to the knowledge

of the research team, no complication or problem was deemed worthy of further investigation or report.<sup>27</sup>

There were 28 low risk and 14 high-risk operations with 21 operations in both effective and ineffective teamwork groups. The mean number of minor problems was 9.5 for pediatrics (95% confidence interval [CI]  $\pm 2.2$ ), and the mean for orthopedics was 13.1 (95% CI  $\pm 5.0$ ). The mean number of operating problems for pediatrics was 5.7 (95% CI  $\pm 1.2$ ), giving an intraoperative performance of 94.1% (95% CI  $\pm 1.3\%$ ), and for orthopedics was 5.0 (95% CI  $\pm 1.4$ ), giving an intraoperative performance of 94.2% (95% CI  $\pm 1.5\%$ ). Figure 3 shows the categories of minor and operating problems that were observed in the 42 operations. The problems occurring most frequently were distractions (eg, telephones, pagers going off, or other people entering the operating room to talk to one of the operating team), which were found more frequently during the orthopedic operations but did not seem to result in operating problems on these occasions. Communication and coordination was the most frequent cause of operating problems, particularly in pediatric cardiac operation that requires a large team to carry out inter-related tasks simultaneously. Patient-specific difficulties (eg, an unusual anatomy requiring an change in technique or strategy) were also more frequent and more problematic in pediatric cardiac operation. Although the incidence of equipment-related problems was high in both operating room environments, these problems were particularly disruptive to orthopedic operation, which depends on the availability and function of procedure-specific instruments rather than traditional scalpel-and-suture skills alone. Diagnostic failures, decision-making failures, and fault resolution problems (eg, failure to find the cause of a problem) were infrequent in both types of operation, and the higher rate of expertise and skill failures in orthopedics was largely because this type of operation offered considerably more opportunity for training.

Results from the 3 linear regressions are found in Table II. Two orthopedic operations using new techniques involved an unusual number of minor problems (eg, surgeon had difficulty operating equipment, re-calibration was necessary due to incorrect use of the equipment, scrub nurse was not trained to use equipment, and then supplied it to the surgeon at the wrong time). Omission of these outlying cases generated a more robust sample for the statistical considerations. These linear regressions suggested that, for every 3 minor problems

**Table III.** Case report of a compensated major problem

A 12-day-old infant with transposition of the great arteries was undergoing an arterial switch operation. The most critical part of this procedure is the transfer of the coronary arteries to the reconstructed aorta. This child was found to have a previously undiagnosed intramural coronary arterial pattern<sup>op</sup>, making the transfer of the coronary arteries much more difficult and much more risky. During the operation, the operative team struggled with a perfusion air lock that resulted in excessive blood in the operative field and reduced visibility at the site of operation<sup>op</sup>. The Consultant Anesthesiologist was called away periodically from the operating room<sup>mp</sup> and his Registrar, who was not familiar with this type of operation, made a number of non-critical errors in communication<sup>mp</sup> and equipment operation<sup>mp</sup>.

Nearing the end of the operation, the Surgeon, who was keen to assess the perfusion of the coronary arteries, removed the aortic clamp without the usual verbal announcement<sup>op</sup>. As the heart began to beat, the Consultant Anesthesiologist returned to the operating room and a non-operating Surgical Registrar entered to discuss the case<sup>mp</sup> while the operative team were watching the heart regaining its contractility. Six minutes later, the Surgeon realized that he had forgotten to close the atrial septostomy<sup>MP</sup> and reconfigured immediately the perfusion to allow him to complete the procedure. Ten minutes later, the septostomy had been closed, and the operation was completed without further incident.

<sup>mp</sup>, minor problem (4 in this report); <sup>MP</sup>, major problem; <sup>op</sup>, operating problem (3 in this report).

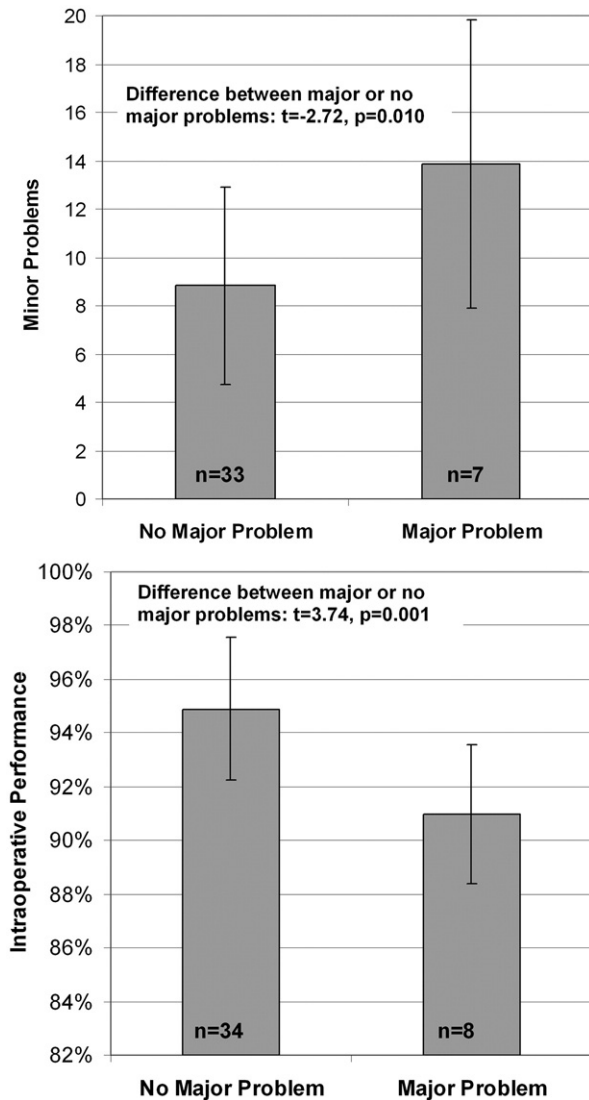
above the 9.9 constant per operation, intraoperative performance was reduced by 1%, with each minor problem being associated with an additional operative duration of 3 minutes 36 seconds. Although there is a considerable amount of unaccounted variation, effective teamwork was related to 3 fewer minor problems per operation, and the consequent improvement in performance and reduction in operating time was suggested by this co-linearity, which can be seen in Figure 4.

Although intraoperative performance was a measure of how smoothly the operation progressed and was not related directly to patient outcome (for example, an operation achieving 95% performance might result in a worse patient outcome than one that achieved 90% performance), the importance of this measure for safety was confirmed by the 8 major problems that were observed. These events did not result in a measurable change in outcome for the patient, but, nonetheless, did threaten the possibility of an accident or incident. Table III provides an example. These operations show a lower intraoperative performance score ( $t = 3.739$ ,  $df = 40$ ,  $P < .005$ ) and a higher minor problem score ( $t = -2.722$ ,  $df = 38$ ,  $P < .05$ ), shown in Figure 5. Effective team performance was found in only one major problem, with 3 of the major problems resulting directly from ineffective teamwork (for example, poor team decision-making lead to a confused hemofiltering plan and failure to return filtered blood to the patient. This was noted fortuitously and dealt with expeditiously). Finally, all major problems occurred in the higher risk operations, and all but one occurred in pediatric cardiac operation.

## DISCUSSION

Our study supports the hypotheses that complications during operations can arise from an escalation of smaller problems and that effective teamwork can mitigate these problems. In this small sample of competent practitioners, it was not a lack of technical knowledge and skills that were the cause of these problems, but the context in which the operation took place. The problems identified in these operations reflected individual errors by members of the team, failures in group processes, unnecessary distractions, difficulties with equipment, unexpected problems with patient anatomy, unexpected or particularly difficult tasks, deficiencies in the culture of safety, and conflicting demands on members of the operating team from other parts of the hospital system. Often these events disrupted the operation, and sometimes they created situations that threatened the safety of the patient or the success of the treatment. Problems were shown to be more frequent and had more severe consequences in high-risk operations with ineffective team performance.

Often events beyond the control of individuals combine to create the situations in which errors are likely to occur. The ability of individuals to work together to identify, avoid, trap, or mitigate failures may affect ultimately the outcome. Single minor problems—for example, a ringing phone or a malfunctioning monitor—were found to be independent of operative risk; however, because they reduce the capacity of the operating room teams to identify and compensate for other unavoidable problems<sup>5</sup> (such as difficult anatomic features), they increase inevitably the challenge and hazards



**Fig 5.** Major problems as a function of minor problems (*top*) and intraoperative performance (*bottom*), with 95% confidence intervals.

of the operation. These events are common and may persist unnoticed in everyday practice, but they may be avoided or mitigated if their importance is appreciated. Decreasing the number of minor problems will improve the management of all operations, and of higher risk cases in particular. Thus, the control of seemingly innocuous events (for example, removing distractions from the operating room or ensuring that all appropriate equipment is available before beginning the operation) may be the most important opportunity to improve the safety of the operating room environment. Dealing with avoidable minor problems increases the capacity to manage unavoidable ma-

ior problems successfully. This approach has been shown to be effective in other industries.<sup>28</sup>

Effective teamwork can be defined by the ability to reduce the impact of otherwise unavoidable problems, whereas ineffective teamwork creates new problems. These essential skills have been recognized in the aviation industry for several decades, where ineffective teamwork has been shown to cause unsafe situations and to impair the ability of a team to recover from difficulties or events critical to safety.<sup>4,29</sup> In many healthcare environments, there is no formal training in team skills, so operating team performance is improvised and evolves unsystematically, rather than being developed, taught, and managed in a more formal manner. Individuals familiar with one another may perform well together in uncomplicated operations, but with increasing intraoperative difficulties, these interpersonal relationships become less effective, sometimes preventing resolution of the problems. Training in team skills is important to prevent small problems, which are latent and often hidden deep within the healthcare system, from cascading toward catastrophe.<sup>3</sup> Experience in aviation,<sup>20,30</sup> the basis for this study, provides evidence from which to evaluate these 'non-technical' skills in healthcare and to develop this type of training.<sup>31,32</sup> We encourage the continued development and evaluation of such programs in healthcare.<sup>33</sup>

Although much is known already about why errors occur and how they can be avoided,<sup>34-36</sup> a culture of blame may make intraoperative error something to be feared, ignored, or concealed rather than studied, understood, and prevented. This study was not welcomed universally by the staff, reflecting a prevailing culture of unease about personal scrutiny in the British National Health Service (NHS). This apparent unease of the staff did not invalidate the result but rather created a smaller sample than would have been obtained ideally, and thus limited the confidence of these results. Our experience in this study persuaded us that a cultural change in the attitude of operating room staff to human error is required to allow these methods of objective analysis to be accepted. Better data may then be gathered, and a more open, safer, and fairer system may be created.

If complications during operations are to be reduced, training in team skills and the management of known, but usually tolerated, minor problems may provide the best opportunity. In this study, the 2 teams worked to high standards, and all operations studied led to successful clinical outcomes. Such features are not yet dependable in the NHS or other healthcare systems. It is likely that

the more general application of these methods may identify opportunities for systems improvements and cultural change throughout the healthcare field. A further study to evaluate the effect of this intervention is now being undertaken by the same research team. In the opinion of the authors, this essential change would have taken place already if, as in aviation, it had been mandated by appropriate legislation and had obtained the commitment of the highest level of management to provide the necessary resources and training.

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