ARTICLE

A System of Analyzing Medical Errors to Improve GME Curricula and Programs

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ABSTRACT

The report of the Institute of Medicine (IOM) *To Err is Human* recommended that both mandatory and voluntary event-reporting systems be established to identify and learn from errors. Because of the tight coupling of graduate medical education (GME) programs and the delivery of care, any event-reporting system used in a teaching hospital should be able to document the types of errors that are being made by graduate medical trainees (GTs).

The authors performed an analysis of the root causes of events involving GTs that were recorded in hospital-based near-miss reporting systems. The root causes were classified using the Eindhoven Classification Model, medical version. Case histories of three separate events, one from an accident and emergency department in the United Kingdom, and two from a large teaching hospital in the United States, are used to illustrate the method.

In all three cases, lack of knowledge on the part of the trainee contributed to the incident. Inadequate educational preparation had the potential for causing significant harm to the patient. Organizational causes were also present in each case, which illustrates the need to examine not only educational issues but also procedural and management issues related to GME. In each case, the analysis revealed in striking clarity deficiencies of educational content and problems of program structure. The authors conclude that doing a root-cause analysis in conjunction with a near-miss event-reporting system in a teaching hospital can be a valuable source of documented information to guide needed educational and system changes to GME programs.

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The report of the Institute of Medicine (IOM) *To Err is Human*,[1] released in November 1999, has generated considerable public interest in issues related to medical errors and improved patient safety. Presidential executive orders and legislation initiated by Congress have been enacted to begin to deal with the issues of medical errors addressed in the report. An important aspect of any discussion of medical errors is the relationship between the delivery of patient care and graduate medical education (GME). Hospitals around the world depend upon graduate medical trainees (GTs)—known in North American GME as interns, residents, and fellows—to deliver major portions of care to patients. GTs are often placed on what Reason[2] refers to as the sharp edge, closest to the action, where an error can be critical to patient safety. But as the following background discussion makes clear, errors by GTs do occur. With that in mind, we wrote this article to explain a system of analyzing the root causes of GTs' medical errors. We give specific case examples to illustrate how information gained from such analysis can be used to identify problems of educational content (hopefully leading to curricular changes) and deficiencies in program structure in teaching hospitals that affect GTs' training.

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BACKGROUND

The linking of education and the delivery of patient care in GME has created what Perrow[3] defines as a tightly coupled system, where errors in one part of the system place other

components at significant risk. The learning process is filled with error as the learner tries to develop and refine the knowledge, skills, and attitudes necessary to fulfill his or her new professional role. In many error-critical situations (where even a minor error can have disastrous consequences) such as aviation, this learning process takes place in a protected environment such as a simulator to minimize risk to the public, the teacher, and the learners themselves. However, this is not always the case in medicine, especially in teaching hospitals, where GTs deliver a significant level of care to patients.

There has been growing criticism of GME as it relates to medical errors and the risk to patients. Both Leape[4] and Ennis[5] have outlined some of the problems of this tight coupling of GME and patient care delivery. Wu[6,7] has examined how residents learn from their mistakes and how they cope with errors. O'Neal et al.[8] found that GTs were willing to report errors in a confidential reporting system, and that their self-reporting was as effective in identifying adverse medical events as medical chart audit. Denisco et al.[9] and Jacques et al.[10] have looked at the performances of GTs in relation to sleep deprivation. Recent books have discussed problems of GME and errors. Robins,[11] in her review of the well-publicized Libby Zion incident in the United States, concludes that lack of adequate supervision of trainees was a major contributing factor in the death of Libby Zion. Duncan,[12] in his observational study of GME, notes problems such as lack of supervision, excessive work hours leading to sleep deprivation, and inadequate formal educational programs. Feinstein[13] raises issues of supervision by faculty as a significant issue that requires changes so that learners can better manage errors.

While there is an acceptance of the fact that GTs make errors, there has been little consensus on how best to deal with the issue. Lack of information about the types and causes of errors by GTs is a major limitation in dealing with both structure and content of the educational programs and their effects on the delivery of care. One way to obtain the necessary information about medical errors by GTs is through an analysis of the root causes of those errors ("root-cause analysis"), as presented in hospital event reports.

The IOM report[1] recommended "identifying and learning from errors through the immediate and strong mandatory reporting efforts, as well as the encouragement of voluntary efforts, both with the aim of making sure the system continues to be made safer for patients." In the wake of this report, there has been increased emphasis placed on using event reporting as an error-management tool. Freitag and Hale[14] have provided a useful definition of an event as a deviation in an activity or technology that leads towards an unwanted, negative consequence. Events can be classified in three different categories: sentinel events/misadventures, no-harm events, and near misses.

- A *sentinel event/misadventure* is an event in which death or harm to a patient or harm to the mission of the organization has occurred.
- A *no-harm event* is an event that has occurred but resulted in no actual harm although the potential for harm may have been present. Lack of harm may be due to the robust nature of human physiology or pure luck. An example of such a no-harm event would be the issuing of an ABO incompatible unit of blood for a patient, but the unit was not transfused and was returned to the blood bank.
- A *near miss*, as defined by Van der Schaaf,[15] is an event in which the unwanted consequences were prevented because there was a recovery by identification and correction of the failure, either planned or unplanned.

The IOM report[1] recommends that mandatory reporting systems concentrate on sentinel events where death or severe harm has occurred. Voluntary reporting efforts, on the other hand, should concentrate on no-harm and near-miss events, which do not result in harm but where the potential for harm is present.

Voluntary near-miss reporting systems have proven to be extremely useful in error management in a number of industries including aviation,[16] nuclear power,[17] and petrochemicals.[15] Barach and Small[18] reviewed the literature on non-medical near-miss reporting for implications for application in the medical domain. They state that

> evaluation of successful non-medical domains indicates that the following factors are important in determining the quality of incident reports and the success of incident reporting systems: immunity (as far as practical); confidentiality or data de-identification (making data untraceable to caregivers, patients, institutions, time); independent outsourcing of report collection and analysis of peer experts; rapid meaningful feedback to reporters and all interested parties; ease of reporting; and sustained leadership support.

Helmreich[19] indicates that because event reports are voluntary, they do not provide data on base rates of risk and error.

Near-miss event-reporting systems have also been developed and tested in different domains in medicine, including emergency medicine,[20] anesthesia,[21] and transfusion medicine.[22,23] To date, most event-reporting systems have been domain-specific or limited to a single department or service within the hospital. Van der Schaaf points out the advantages of establishing hospital-wide event-reporting systems:

> The combining of databases of causal factors from all departments of the same hospital could lead to the early identification of hospital-wide emerging structural causes of incidents, errors, and deviations, and (because of their latent nature) greater visibility of causal factors for organizational learning. The possibility of benchmarking against the performance of other departments, and the unique feedback that academic hospitals, in particular, could receive from such a system, may be used to improve the medical school curriculum.[24]

Because of the tight coupling of the educational programs and the delivery of care, any near-miss reporting system used in a teaching hospital should be able to document the types of errors that are being made by GTs.

ROOT-CAUSE ANALYSIS

The root-cause-analysis approach described in this article is part of the Medical Event Reporting System for Transfusion Medicine (MERS-TM). MERS-TM is a prototype, national, event-reporting system for blood centers and hospital transfusion services. The attributes and the development of MERS-TM have been previously described by Battles et al.[22] The application of the system of analysis of the causes of events in transfusion medicine has been described by Kaplan et al.[25] The expansion of MERS-TM as a method for hospital-wide event reporting is currently under development in selected teaching hospitals that are already using MERS-TM.

There are two main classifications of errors (i.e., failure)—active and latent. Reason[2] defines active failures as errors and violations committed by those in direct contact with the human–system interface. Active failures are what are commonly referred to as human errors. Reason defines latent, or system, errors as the delayed consequences of technical design or organizational issues and decisions. Accidents (as defined in the human-error literature) and adverse events happen when latent conditions, such as system failures, combine with an active human error. Thus, error researchers stress the importance of both examining active human errors and also looking at underlying system issues that can contribute to error. Reason has referred to these latent or system errors as "organizational pathogens," which lie waiting for the right opportunity to become active. He stresses studying the latent conditions that may well set up humans for failure. Van der Schaaf[15] emphasizes that it is important to document how health professionals identify errors and recover from combinations of active and latent conditions, thus preventing events from having adverse consequences.

The causal coding system used in MERS-TM is based on the Eindhoven Classification Model (ECM) originally developed by Van der Schaaf[15] to classify root causes identified in the causal trees of safety-related incidents in the chemical process industry in The Netherlands. This system has been successfully tested in other industrial settings as well as in the medical setting.[20,22,23,26,27] We slightly modified this system and created the medical version of the ECM for the MERS-TM causal classification, which is shown in Table 1. The ECM focuses on three main types of causes separately, and in a predefined order: technical, organizational, and human. Technical problems are considered first, such as problems of the design of equipment, software, labels, and forms, and construction problems, such as improper installation of equipment, or unexplainable material defects.

Considered second is the group of root causes that focuses on the organizational level, examining standard operating procedures, organizational decisions and priorities, culture, and transfer of knowledge. Only after looking at possible technical and organizational problems is the third group of causes—the human (i.e., active) factors—considered. This order is chosen to counteract the sometimes-strong bias within organizations to start and stop analysis at the level of the employee as the end-user, and leave unquestioned the technical and organizational (i.e., latent) context of any mishap.

Rasmussen[28] has provided a useful human behavioral taxonomy for the active errors. His classification begins with knowledge-based decision making at the top of a hierarchy of actions or decisions. Knowledge-based behavior involves the conscious application of existing knowledge to manage novel situations. Rule-based decision making involves the application of existing rules or schemes to manage familiar situations. It requires no prolonged, active processing, but simply the selection and application of the appropriate rule. Skill-based behavior refers to "automatic" tasks requiring little or no conscious attention during execution.

In this system, when an event is reported, it is investigated and the results are recorded using a causal tree format. The causal trees are used to visually represent, chronologically, the critical antecedent activities and decisions that led to the event and its recovery, if any. Although there may appear to be one "primary root cause," it is the combination of causes that is the richest source of information. Tree construction is stopped when all known antecedents and their causes have been included and the investigator reaches a point beyond which investigation is not practical (outside the boundary of the investigating organization or ability to make changes). The "root causes," which constitute the bottom layer of the causal tree, are classified using the ECM to code the root causes. The information about the event and its casual tree is then placed within a database.

A COMPARISON STUDY

In order to test the reliability of the causal classification process, we carried out a comparison study. Twenty-five cases

Table 1

Classification of Root Causes of Medical Errors*

Code	Category	Definition
	Latent errors	**Errors that result from underlying system failures**
	Technical	Refers to physical items such as equipment, physical installations, software, materials, labels, and forms
TEX	External	Technical failures beyond the control and responsibility of the investigating organization
TD	Design	Inadequate design of equipment, software, or materials; can apply to the design of workspace, software packages, forms, and label design
TC	Construction	Correct designs that were not constructed properly; examples include incorrect set-up and installation of equipment in an inaccessible area
TM	Materials	Material defects found; examples could be the weld seams on blood bags, defects in label adhesive, or ink smears on preprinted labels or forms
	Organizational	
OEX	External	Organizational failures beyond the control and responsibility of the investigating organization
OP	Protocols/Procedures	The quality and availability of protocols that are too complicated, inaccurate, unrealistic, absent, or poorly presented
OK	Transfer of Knowledge	Failures resulting from inadequate measures taken to ensure that situational or site-specific knowledge or information is transferred to all new or inexperienced staff
OM	Management Priorities	Internal management decisions in which safety is relegated to an inferior position when there are conflicting demands or objectives; this is a conflict between production needs and safety—an example of this is decisions made about staffing levels
OC	Culture	A collective approach, and its attendant modes, to safety and risk rather than the behavior of just one individual; groups might establish their own modes of function as opposed to following prescribed methods—an example of this is not paging a manager on the weekend because that was not how the department operated; "It's just not done."
	Active errors	**Errors or failures that result from human behavior**
HEX	External	Human failures originating beyond the control and responsibility of the investigation organization
	Knowledge-based behaviors	
HKK		The inability of an individual to apply his or her existing knowledge to a novel situation—an example is a trained technologist unable to solve a very complex antibody identification problem
	Rule-based behaviors	
HRQ	Qualifications	The incorrect fit between an individual's qualification, training, or education and a particular task—an example would be expecting a technician to solve the same type of difficult problems as a technologist would
HRC	Coordination	A lack of task coordination within a health care team in an organization—an example would be an essential task not being performed because everyone thought that someone else had completed the task
HRV	Verification	The incorrect or incomplete assessment of a situation, including related conditions of the patient/donor and materials to be used before beginning the task—an example would be failure to correctly identify a patient by checking the wristband
HRI	Intervention	Failures that result from faulty task planning and execution; this would be selecting the wrong rule or protocol (planning) or executing the protocol incorrectly (execution)—an example would be washing red cells by the same protocol as that used for platelets
HRM	Monitoring	Monitoring of process or patient status—an example could be a trained technologist operating an automated instrument and not realizing that a pipette that dispenses reagents is clogged

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Table 1 (Continued)

Code	Category	Definition
	Skill-based behaviors	
HSS	Slip	Failures in the performance of highly developed skills
HST	Tripping	Failures in whole-body movement; these errors are often referred to as "slipping, tripping, or falling"—examples would be a sample tube slipping out of one's hands and breaking, or tripping over a loose tile on the floor
	Other factors	
PRF	Patient-related Factors	Failures related to patient/donor characteristics or actions that are beyond the control of the health professional team and influence treatment—an example would be a patient who deliberately uses another patient's identity card in seeking treatment
	Unclassifiable	**Failures that cannot be classified in any of the current categories**

*This causal coding system is based on the Eindhoven Classification Model and was adapted by the authors for use as part of the Medical Event Reporting System for Transfusion Medicine, a prototype, national event-reporting system for blood centers and hospital transfusion services. See the text for details.

derived from emergency medicine and intensive care were put into causal tree form but not classified as to cause. Trained investigators (including us) from two groups in The Netherlands and the United States independently classified these cases. A similar set of transfusion cases were also classified independently by both groups. When the results were compared for correlation/associations using Yule's Q, a correlation of 0.86 was achieved. This consistency of the application of the classification system across various medical domains would indicate that the causal classification is reliable within the participating institutions.

To illustrate how event reporting and associated root-cause analysis can be used to identify, study, and classify near-miss events involving GTs, the authors selected three cases that they had investigated and for which they had conducted root-cause analysis. The three cases come from two domains of medicine and two countries.

Case 1. A patient was almost sent home with a fractured cheekbone late on a Friday night from an accident and emergency (A & E) department in the United Kingdom. The A & E department was busy that night and was staffed by two GT2s and one GT3 (i.e., second-year and third-year trainees). No supervising faculty member was present during night hours. The patient's condition suggested that a fracture was unlikely. The GT2 was having difficulty in reading the X-ray and failed to spot the fracture. A second GT2 also on duty looked at the X-ray and could not find the fracture. An experienced senior charge nurse overheard the conversation between the two trainees. The nurse viewed the X-ray and immediately identified the fracture. This case is an example of a near-miss event, with the nurse serving as the unplanned recovery mechanism. This event was reported to one of us (CES) by the GT2 involved in the event. The causal tree for this event is shown in Figure 1.

Case 2. During a two-month period, patients were given inadequate drug treatment for acute asthma in an emergency department (ED) of a large public hospital in the United States. The two-month period corresponded to a normal ED rotation for GT2s. A lecture on new treatment protocols for the treatment of acute asthma was normally given to all GT2s at the beginning of their two-month ED rotation. During the period in question, the faculty member responsible for presenting the lecture on asthma management was out of town, and no one else presented the needed materials. The discrepancy in treatment was discovered based upon a chart audit of asthma cases in the ED and investigated by one of us (JBB). The casual tree for this event is shown in Figure 2.

Case 3. The last case is an example of a no-harm event where there was no harm to the patient but the potential for harm was significant. A labor-and-delivery patient in a large public hospital who had an uncertain blood type received a transfusion of two units of A+ blood. Blood for the patient had been ordered from the hospital transfusion service based on a sample taken from the patient and cross-matched and compared with the historical type listed in the laboratory information system computer. The A+ blood was delivered to the unit. However, the GT3 noticed that the patient record on the unit (shadow record) indicated that the patient's blood type was recorded as O+. The GT3 immediately ordered O− blood (since the standard procedure was to use O− blood when the blood type is uncertain) and had another blood sample drawn. Prior to the arrival of the O− blood units, the patient's condition became critical and the GT3 had one of the A+ units administered. The O− units arrived, but the GT3 resident administered the second unit of A+ blood anyway, indicating that the patient had now been sensitized to A+, since no transfusion reaction

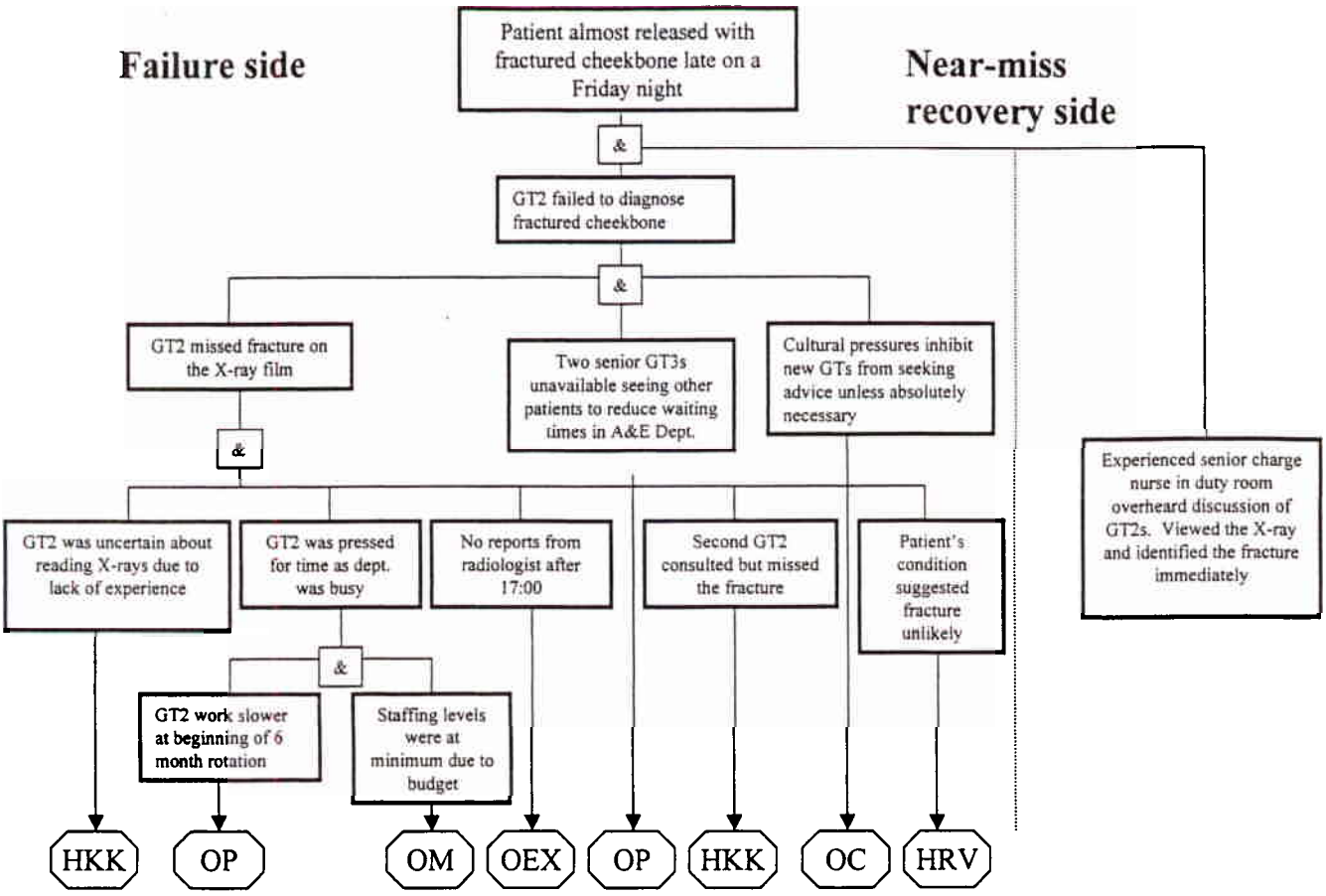

Figure 1. The causal tree describing a near-miss event involving a fractured cheekbone, from an accident and emergency department. The acronyms at the very bottom of the figure are classification codes for the various events shown in the tree. For example, "OK" indicates an organizational failure in transfer of knowledge. See Table 1 for definitions of these codes. The dotted vertical line without a code indicates the separation between the failure side and the recovery side of the casual tree.

had occurred. The results of the second cross-match confirmed the patient was in reality A+ and had been administered the correct blood product. It was concluded that the blood type listed in the shadow record had been incorrectly entered. This event was documented by the transfusion service. This case is a classic example of a no-harm event where no harm occurred to the patient. However, if the patient's blood had actually been O+, serious harm or death could have occurred. Figure 3 displays the causal tree for this case.

DISCUSSION

Case 1 is a classic example of a near-miss event. The timely intervention of the senior charge nurse served as the recovery step. Often such cases go undocumented because there was no harm done. However, failure to record the issues of lack of knowledge in reading X-rays would have meant that this important deficiency would have remained unknown. Supervising faculty had made an assumption that all GT2s had acquired skills in X-ray reading based on medical school training. In reality, other events reported from the same A & E department indicated that most assigned GT2s had similar difficulties in reading X-rays at the beginning of their A & E rotations. When a pattern of events with the same root causes was seen over time, the faculty had to question their assumptions about the entry-level skills of the GT2s. Special training in reading X-rays at the beginning of an A & E rotation was initiated. Case 1 also illustrates the importance that senior health care professionals often play in preventing serious errors that can be made by GTs. Their actions are often an unrecognized critical element in patient safety.

Case 2 illustrates how often educational activities are tightly coupled with patient care. Failure to deliver one key lecture resulted in less than optimal care being provided by

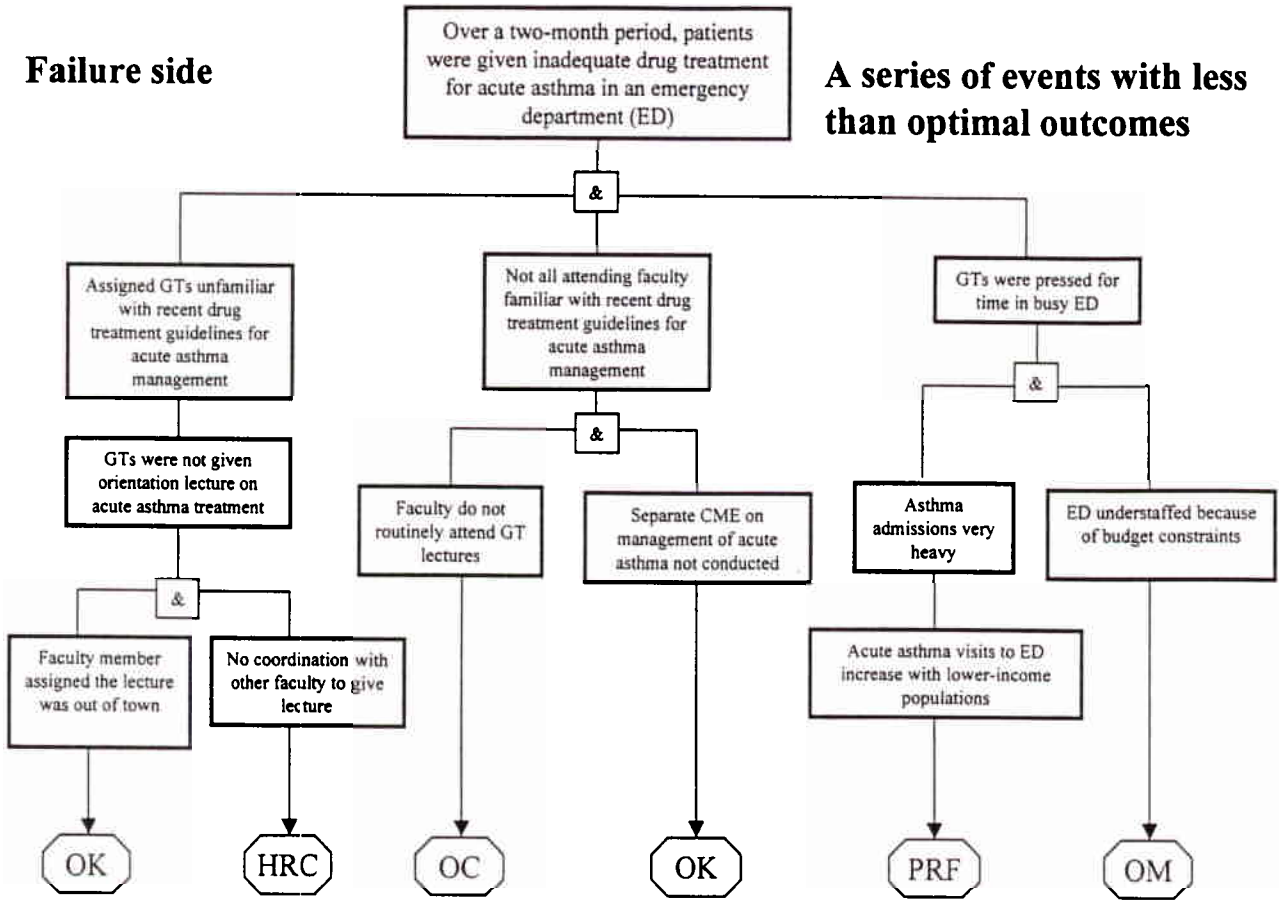

Figure 2. The causal tree describing an inadequate treatment of acute asthma, from an emergency department. The acronyms at the very bottom of the figure are classification codes for the various events shown in the tree. For example, "HRC" indicates a human error involving a lack of coordination within a health care team. See Table 1 for definitions of these codes.

the GTs. Alternative methods of providing critical information on an as-needed basis are often lacking in GME programs. The latent failure of the shadow record in case 3 points out how such failures often set up the GT for an error. In this case the mismatch between the shadow record and other available patient records caused the uncertainty about the patient's blood type. This latent failure of the medical record system combined with the GT trainee's rule-based failure in confusing Rh factors rules with ABO rules could have led to a sentinel event. However, luck prevailed and no harm was done to the patient. Other reported cases have indicated that GTs' knowledge of critical issues of transfusion medicine was lacking. These GTs were relying on information that had last been presented to them in the second year of medical school and inadequately reinforced during GME.

In all three cases, lack of knowledge on the part of the trainee contributed to the incidents. Inadequate educational preparation had the potential for significant harm to the patient. Organizational causes were also present in each case, which illustrates the need to examine procedural and management issues relative to GME. In each case, issues of both educational content deficiencies and program structural issues became strikingly clear. This information can be powerful documentation to reveal trainees' educational needs within the context of patient care delivery.

RECOMMENDATIONS

Conducting root-cause analysis on near-miss events can be a valuable source of information to make needed educational changes to graduate medical education programs both in content and in structure. As near-miss reporting systems gain wider acceptance in teaching hospitals, their use as an evaluation tool for GME should be encouraged. Directors of medical education in teaching hospitals should become actively involved in the design and utilization of event-reporting systems within their respective hospitals. Residency directors should use data from hospital near-miss reporting

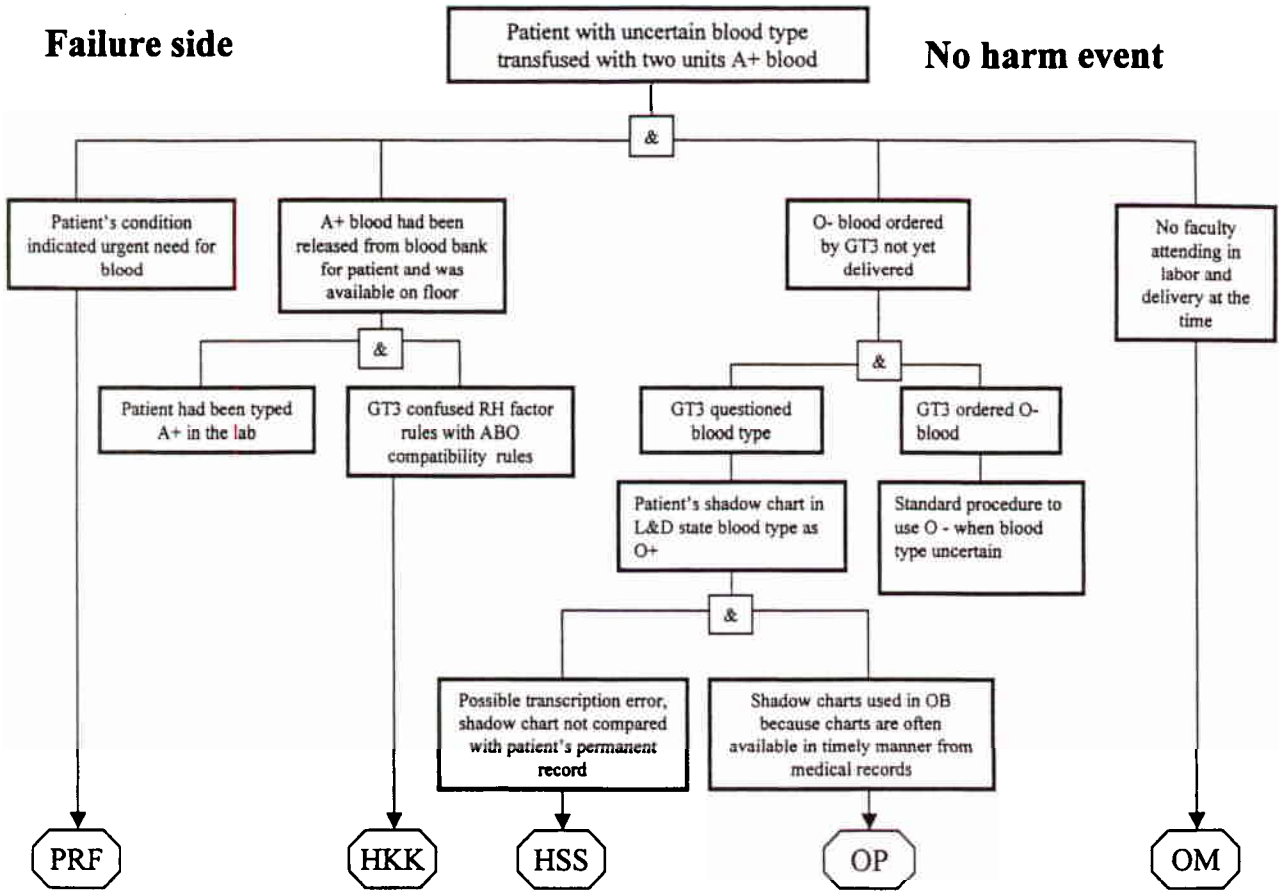

Figure 3. The causal tree describing a no-harm event involving blood transfusions, from a large public hospital. The acronyms at the very bottom of the figure are classification codes for the various events shown in the tree. For example, "OM" indicates problems with setting organizational management priorities. See Table 1 for definitions of these codes.

systems as part of their overall program-evaluation efforts. The use of near-miss reporting data should be included as an essential part of accreditation of any GME program. The information obtained on errors made by GTs can be used to provide feedback on the effectiveness of aspects of undergraduate medical education as well. In this regard, direct performance information can be useful in determining educational priorities for the medical school curriculum.

Near-miss reporting systems can be effective error-management tools. It has been shown that GTs are willing to report errors if they are provided with a no-fault confidential reporting mechanism. The tight coupling of GME and the delivery of patient care requires that actual and potential errors of GTs be monitored and that the information obtained be used for program improvement and patient safety.

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