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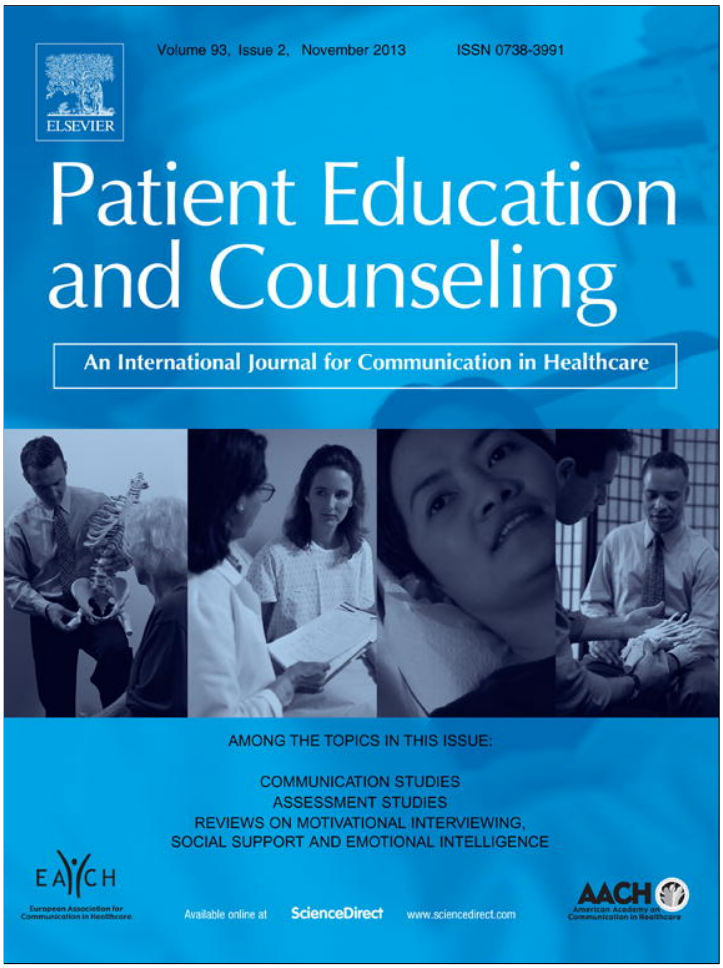

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Patient Education and Counseling 93 (2013) 230–238

Contents lists available at SciVerse ScienceDirect

Patient Education and Counseling

journal homepage: www.elsevier.com/locate/pateducou

Assessment

TRACEing the roots: A diagnostic "Tool for Retrospective Analysis of Critical Events"

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ARTICLE INFO

Article history:
Received 5 October 2012
Received in revised form 14 June 2013
Accepted 24 June 2013

Keywords:
Critical incidents
Human factors
Medical errors
Incident analysis
Quality improvement
Patient safety

ABSTRACT

Objective: The lack of interdisciplinary clarity in the conceptualization of medical errors discourages effective incident analysis, particularly in the event of harmless outcomes. This manuscript integrates communication competence theory, the criterion of reasonability, and a typology of human error into a theoretically grounded *Tool for Retrospective Analysis of Critical Events* (TRACE) to overcome this limitation.
Methods: A conceptual matrix synthesizing foundational elements pertinent to critical incident analysis from the medical, legal, bioethical and communication literature was developed. Vetting of the TRACE through focus groups and interviews was conducted to assure utility.
Results: The interviews revealed that TRACE may be useful in clinical settings, contributing uniquely to the current literature by framing critical incidents in regard to theory and the primary clinical contexts within which errors may occur.
Conclusion: TRACE facilitates a comprehensive, theoretically grounded analysis of clinical performance, and identifies the intrapersonal and interpersonal factors that contribute to critical events.
Practice implications: The TRACE may be used as (1) the means for a comprehensive, detailed analysis of human performance across five clinical practice contexts, (2) an objective "fact-check" after a critical event, (3) a heuristic tool to prevent critical incidents, and (4) a data-keeping system for quality improvement.
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Contents

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http://dx.doi.org/10.1016/j.pec.2013.06.019

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1. Introduction

Recent developments in the health care environment encourage open and transparent communication in response to critical incidents in medicine. For example, the Institute of Medicine (IOM) mandates reporting of all serious and preventable adverse events [1], the Joint Commission requires hospitals to disclose all unanticipated outcomes to patients [2], and the National Quality Forum recommends "safe practice" guidelines to support health care professionals in responding to adverse events [3].

Among the many challenges faced by medical practitioners and institutions in competently performing a critical incident analysis is a lack of conceptual clarity in regard to error-related terminology. Few clinicians appreciate the important but fine distinctions that are made by legal and medical experts in the field when using such terms as mistakes, slips, lapses, near misses, harmless hits, close calls, accidents, and complications or the ambiguity associated with key moderators such as preventability, predictability, controllability and intentionality. The resulting confusion can easily intimidate and discourage any type of critical incident analysis.

Beyond conflicting reporting guidelines and confusing terminology, interpersonal communication has received far less attention in the existing literature than its importance would merit. Communication has been shown to be a significant element in patient safety incidents [4–9] and malpractice claims [10,11], but investigations infrequently address the specific clinical context (i.e., medical history assessment, diagnosis, treatment planning, treatment execution, and post-treatment care) within which communication errors may have taken place as a precursor to a critical event. Moreover, current incident analyses merely examine communication as a dichotomous variable.

The purpose of this manuscript is a systematic integration of the existing interdisciplinary literature to facilitate the development of a practical assessment tool that overcomes these limitations, with the ultimate goal of supporting a more effective and comprehensive identification and analysis of critical incidents in medicine. Such a tool needs to advance a clearer conceptualization of medical errors and assesses all types of critical events, including those that cause little or no harm. Furthermore, it needs to integrate theories from different academic fields to facilitate a grounded, interdisciplinary evaluation of critical events. It is in this arena that our proposed *Tool for Retrospective Analysis of Critical Events* (TRACE) may be seen.

2. Methods

2.1. Organization of terminology and conceptual integration underpinning TRACE

The first author conducted a systematic review of the comprehensive existing literature on critical incidents to organize and integrate the related terminology as a first step toward creating the TRACE. The full body of literature from the fields of medicine, psychology, and communication were included. The search terms encompassed all related terminology (i.e., "critical incident(s)", "critical event(s)", "adverse event(s)","near miss(es)", and "error(s)"; each in combination with the term "medicine"). The second step entailed the integration of medical performance in regard to intrapersonal and interpersonal activities into the TRACE using three theoretical frameworks from the psychological, ethical and communication literature: (1) Reason's typology of human error [12], (2) Banja's criterion of reasonability [13], and (3) Spitzberg and Cupach's communication competence theory [14,15].

2.1.1. Typology of human error

Reason [12] argues that human errors occur during three cognitive stages: (1) planning (i.e., errors in identifying a goal and deciding on the means to achieve it), (2) storage (i.e., lapses), and (3) execution (i.e., slips). Based on this contention, Reason conceptualizes human error as the failure of actions to be completed as intended (i.e., "errors of execution", which entail slips and lapses), and (2) the use of a wrong plan to achieve an aim (i.e., "errors of planning", which include mistakes). From this conceptualization, Reason derives a threefold typology of human errors: (1) skill-based slips and lapses (execution failures in the implementation of the stored plan), (2) rule-based mistakes (failure of expertise that caused a plan to be applied inappropriately), and (3) knowledge-based mistakes (lack of expertise or resource limitations that force a plan to be worked out from first principles).

2.1.2. Criterion of reasonability

Banja [13] argues that existing definitions of errors in medicine disregard the occurrence of factors that lie beyond a provider's reasonable control. He suggests that a valid conceptualization of medical errors needs to integrate whether or not there was anything a provider could have *reasonably* done to avert the mishap, other than not to perform the action at all. Based on this contention, Banja introduces a *standard of care* criterion and conceptualizes human error in medicine as "an unwarranted failure of action or judgment to accommodate the standard of care" (p. 7).

2.1.3. Theory of communication competence

According to Spitzberg and Cupach [14,15], optimal communication is perceived as effective (i.e., achieving preferred outcomes) and appropriate (i.e., conforming to normative expectations) in a given context. A person's motivation, knowledge, and skills facilitate such an impression. Thus, a person who is motivated, has the skills, and knows how to communicate appropriately and effectively will be perceived as more competent than others. At the same time, these three factors serve as a diagnostic tool when things go wrong, implying that negative outcomes are always attributable to deficiencies in a person's motivation, knowledge, and/or skills [14].

2.2. Vetting TRACE through stakeholder focus groups and interviews

The first author conducted two focus groups with a total of 12 volunteering attending physicians in the area of family medicine at a large teaching hospital in a Southeastern United States to test the applicability of the TRACE in medical practice. The physicians were recruited by the department chair. All focus group participants had experienced at least one medical error. None of them had actively conducted any research on this topic area.

At first, the participants were given a handout with a visual presentation of the TRACE, along with a detailed verbal introduction. The focus group participants were asked to write out a case study of a harmful or harmless critical incident that involves more than one of the matrix components. The physicians then analyzed their case studies in peer group interactions in an attempt to find out whether the TRACE worked in defragmenting and identifying the contributing factors of their incidents. In a subsequent group discussion, examples were brainstormed for each matrix cell and potential applications of the TRACE were discussed.

In addition, in-depth interviews were conducted with three local health lawyers to validate the applicability of the TRACE to legal practice. After a detailed introduction of the TRACE components, the lawyers were asked to apply the TRACE to some legal scenarios. Finally, expert conversations were conducted with

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two communication scholars to reflect on the applicability of the matrix in light of the communication literature.

3. Results

3.1. Organization of related terminology

A visual illustration of the conceptual relationship among the related terms is presented in Fig. 1. A *critical incident* is defined as a human error or equipment failure that could have led (if not discovered or corrected in time) or did lead to an undesirable outcome of any kind, including death [16]. *Near misses* refer to an event or situation that could have resulted in patient harm but did not, either by chance or through timely intervention [17]. Wu and colleagues maintain that the term *close call* is more appropriate in capturing the medical circumstances associated with these instances than other terminology as it includes both a "near miss" when an error did not reach the patient as well as a "harmless hit" in which the error reached the patient but did not result in any harm or any serious harm [18].

An *adverse event* does result in patient harm and is defined as an injury caused by medical management rather than by the underlying disease or condition of the patient [17]. Serious adverse events have consequences related to prolongation of a patient's hospital stay, measurable disability or death [19,20]. Adverse events can result from human errors, accidents or complications [21]. The definitional key to distinguishing these terms is intentionality, preventability and predictability. The term *human error* can only be applied to *intentional* behaviors that fail for matters beyond one's reasonable control in one of two ways: (1) in identifying an appropriate plan of action to achieve an intended outcome and/or (2) in executing a plan as intended [12].

Preventability implies that methods for averting a given injury were known and that an adverse event resulted from failure to apply that knowledge [22]. If an adverse event is the result of unpreventable factors it is not an error but rather a complication or accident. *Complications* are unpreventable but predictable adverse events (e.g., a marrow depression following chemotherapy), while *accidents* are unpreventable and unpredictable (e.g., an allergic reaction to a drug for the first time) [21].

The definition of *medical error* promulgated by the Institute of Medicine [1] is largely derived from Reason's [12] notion of intentionality in the planning and execution of an action, and includes: "(1) the failure of actions to be completed as intended (i.e., error of execution) and (2) the use of a wrong plan to achieve an aim (error of planning)." While useful as a general point of departure, the IOM operationalization of error has three significant shortcomings. The first is its failure to specify the clinical practice context within which errors occur. The second is the failure to differentiate among types of errors in a coordinated way. Third, the definition fails to differentiate failures from errors; the *failure* to achieve a desired outcome does not necessarily imply a human *error* because some outcomes are unpreventable and/or unpredictable.

Another feature that makes the conceptualization of human errors complex is the fact that they can be attributed to active and latent variables [12]. *Active errors* are associated with "front-line operators" who work at the "sharp end" of complex systems (e.g., physicians, surgeons, nurses, technicians, pharmacists and others in the medical field). *Latent errors*, on the other hand, are attributed to individuals who reside in the regulatory, administrative, and organizational bodies of the health care system, and provide the resources and constraints that form the environment where medical practitioners work [23]. Incident prevention efforts need to concentrate on the discovery and neutralization of active as much as latent errors.

3.2. Theoretical integration

As noted earlier, communication failures have been associated with a variety of adverse events [4–11] suggesting that it may also act as a significant preventive element. Consequently, we integrated Spitzberg and Cupach's communication competence theory into the TRACE to conceptually extend Reason's typology of human errors. This application yielded a typology of (1) motivation-based, (2) knowledge-based, and (3) skill-based errors in communication (i.e., when things go wrong, at least one of the interactants did not have the skills, the knowledge, or the motivation to communicate effectively and appropriately in the given context). Furthermore, this procedure generated a new, comprehensive typology that encompasses medical errors on an

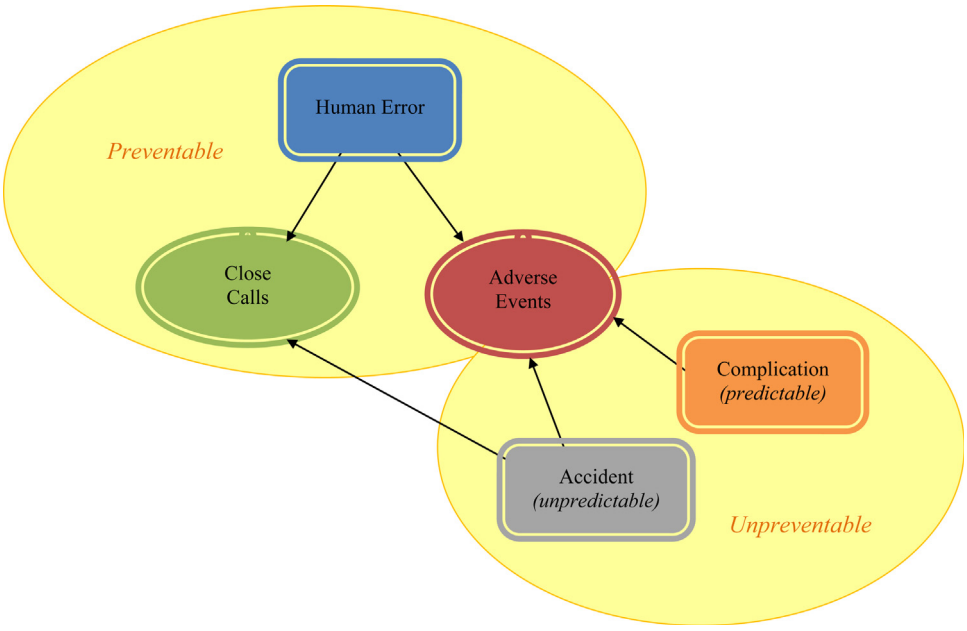

Fig. 1. Delineation of terminology related to critical incidents in medicine.

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(1) intrapersonal dimension that includes knowledge- and rule-based mistakes and skill-based slips and lapses, and an (2) interpersonal dimension that contains communication errors.

Both intrapersonal and interpersonal errors entail active and latent elements, including errors that occur at the front line of medical performance as well as system errors such as, for example, inaccurate handover communication or behavioral slips between surgical team members that can adversely affect patient care. Banja's reasonability criterion adds another layer to each dimension of this conceptualization; for example, on a rule-based performance level, a physician *ought* to have known what rule was applicable, or *ought* to have known that the rule was inappropriate to the situation.

3.3. Stakeholder validations of the TRACE

The TRACE cells captured all elements of the focus group participants' case studies. Furthermore, the participants were able to fill each matrix cell with at least one medical example. The focus group participants suggested that the TRACE could be used as a tool for (1) training (e.g., to inform medical students and practitioners of the full scope of things can go wrong), (2) self-assessment (e.g., for their annual review process), (3) error prevention (e.g., in anticipation of a treatment plan), and (4) institutional critical incident analysis (e.g., as a coding instrument for critical incident reports).

The health lawyers implied that the TRACE could aid in delineating cases of negligence. Particularly the legal conditions "breach of duty" and "causation" were properly identifiable within the TRACE. Also the communication experts validated the TRACE in light of the current communication literature; the matrix encompassed all channels and levels of communication. Furthermore, the communication scholars discussed that the TRACE could be used as an instrument to track the effects of targeted clinical performance interventions.

4. Discussion and conclusion

Recognizing the complex nature of critical incidents that arise during the practice of medicine, we propose the TRACE as a conceptual and practical tool to assist researchers and clinicians to more fully analyze and understand clinical practice, regardless of the occurrence of an adverse event. The matrix is grounded in medical practice through its reference to normative care standards and the clinical functions within which errors occur, ranging from history taking to post-treatment care. Finally, the tool distinguishes error types on intrapersonal and interpersonal performance dimensions, allowing for a differentiated analysis of critical incidents that integrates Reason's typology of human error, Banja's reasonability criterion, and Spitzberg and Cupach's communication competence theory. The following section discusses the components of the TRACE matrix and its potential applications in various medical practice contexts.

4.1. Discussion

4.1.1. Using the TRACE

The matrix displayed in Fig. 2 integrates our notions above into a practical tool for identification and analysis of the factors that contribute to critical incidents. At the top of the TRACE matrix, a critical incident is placed in regard to practice consistent with normative standards or practice outside of standards. The second level of organization addresses the severity of the incident in terms of harm to the patient. Consequently, the first main column of the matrix considers medical actions consistent with standards of care that resulted (1) in a positive and desired clinical outcome (considered good practice), (2) in an unintended outcome with no harm (i.e., a close call, accident, complication, or flawed medical guideline), or (3) in an adverse outcome due to controllable or uncontrollable (e.g., accident, complication, or a flawed medical guideline) circumstances. The third level of organization organizes medical performance into interpersonal and interpersonal clinical actions to identify potential error sources in active and latent motivation, knowledge and skills. This level is important regardless of the good practice notion of the first matrix column, because it can reveal (1) competent intervention strategies with potential errors-in-the-making and (2) information that can be critical for the revision of a potentially flawed medical guideline.

MEDICAL CARE STANDARD			Adherence			Deviation					
						Intended			Unintended		
MEDICAL OUTCOME			As intended	Unintended		As intended	Unintended		As intended	Unintended	
				No harm	Harm		No harm	Harm		No harm	Harm
MEDICAL PERFORMANCE											
INTRA-PERSONAL	Latent	Motivation									
		Knowledge									
		Skills									
	Active	Motivation									
		Knowledge									
		Skills									
INTER-PERSONAL	Latent	Motivation									
		Knowledge									
		Skills									
	Active	Motivation									
		Knowledge									
		Skills									

Fig. 2. Diagnostic Tool for Retrospective Analysis of Critical Events (TRACE).

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The second main column of the matrix contains medical actions that fall outside of standards of care. The TRACE adds conceptual detail to the current literature in this regard by distinguishing between clinical action outside of practice standards that were undertaken intentionally or unintentionally. Banja [13] notes that a variety of factors such as clinical, situational, or social circumstances may warrant a medical judgment or action at odds with standard care or when there are no applicable standards available to guide practice. Building on this argument, it is important to distinguish whether a practitioner's actions outside care standards was purposeful (e.g., "out-of-the-box" reasoning when a guideline does not seem to fit a particular patient case), or unintentional (e.g., an inadvertent misapplication of a medical guideline).

When the action is purposeful and results in a positive clinical outcome, it may be considered a potential innovation (e.g., discovery of a better treatment alternative) or appropriate adaptation (e.g., recognition of an existing guideline's limitations). If the outcome was unintended but harmless to the patient, it would be classified as a close call. Finally, if the outcome caused harm the classification would be a medical error (i.e., the practitioner's practice outside of care standards compromised the patient's health). Thus, the intentional deviation column delineates two closely linked scenarios – the practitioner who contributes innovation to the medical literature or his counterpart who commits a medical error.

An unintentional deviation from medical care standards may be considered a near miss or attributed with good luck if the desired outcome was attained. When the action results in an unintended outcome without harm, it would reflect a harmless hit (i.e., the deviation reached but did not harm the patient), and a harmful error if it results in an adverse event (i.e., the deviation harmed the patient). It is important to note that a deviation from medical care standards alone does not necessarily reflect the extent to which human failure has contributed to a critical event. The third level of organization in the TRACE matrix adds important conceptual depth to this assessment because it accounts for several other error sources on intrapersonal and interpersonal medical performance dimensions.

Banja's definition of medical errors only captures the far right side of the TRACE (i.e., unintended deviations from standards of care), and only if they are deemed unwarranted. Similarly, the IOM definition neglects errors and intervened errors-in-the-making that may have occurred despite positive outcomes (i.e., first column of the matrix) beyond deviations from care standards (i.e., third level of organization in the matrix), and also fails to distinguish between intentional and unintentional nonconformities to practice guidelines that are contained in the second main column of the matrix. In this way, the TRACE clarifies gray areas that existing definitions do not account for and facilitates a more comprehensive and theoretically grounded analysis. The exemplars in Appendix A illustrate three critical incidents that fall into the adherence, intended deviation, and unintended deviation columns of the matrix to demonstrate how the TRACE can be used to conceptually distinguish these cases.

4.1.2. Applying the TRACE to different medical care contexts

A comprehensive application of the TRACE is accomplished by framing critical incidents in regard to the primary clinical contexts within which errors can occur, including (1) medical history assessment, (2) diagnosis, (3) treatment planning, (4) treatment execution, and (5) post-treatment care. The proposed TRACE performance dimensions may carry different weights in these medical contexts. For example, some contexts heavily depend on patient-provider interaction (e.g., history-taking, treatment planning, post-treatment care and discharge planning) and communication among the medical team members (e.g., handover and treatment execution) and thus will likely be more prone to interpersonal errors. Other medical contexts involve more cognitive activity on behalf of the physician (e.g., diagnosis, storage, planning and implementation of treatment) and thus lend themselves more to intrapersonal errors (e.g., misapplication of a medical guideline, cognitive lapses including confusion or forgetfulness, behavioral slips such as a literal slip of a surgical knife, errors in medication choice and dosage, or the false adjustment or setting of medical equipment). The following section briefly discusses the applicability of TRACE to each of these contextual areas.

4.1.2.1. Errors in medical history assessment. Although normative practice in regard to data-gathering and history assessment skills is not often referred to in formal standards, they are considered an important element of patient-centered care in the interpersonal domain. Among patient-centered clinical skills related to data-gathering are question-asking strategies that include open-ended probes, open-to-close question cones, address of relevant psychosocial, emotional and behavioral aspects of a patient's illness experience and active listening techniques. The incorporation of these data-gathering skills (among others) into communication training programs at the undergraduate, graduate and post-graduate level reflects widespread dissemination and professional consensus in regard to normative practice [24].

As reflected in the first matrix column, there is the possibility of rare circumstances in which patient harm may result regardless of good interviewing practices. For example, a patient may not have disclosed an important medical history event or lifestyle behavior even if the questions were posed in a non-judgmental and sensitive manner because of shame, repression of the memory, or misinterpretation of the question. In this instance, failure of the data-gathering process could not have been predicted or controlled by the clinician and thus would not be considered a medical error. Alternatively, this column may suggest necessary revisions of the current practice standards and point at particular history-taking practices that need improvement (e.g., latent or active motivation, knowledge, and/or skills). For example, institutional efforts to inform clinicians about competent interviewing practices (i.e., knowledge), to illustrate the effects of such practices (i.e., motivation), and to teach how to implement them (i.e., skills) may need to be enhanced.

Because the conduct of a history relies on dyadic exchange, history-taking errors are most likely to occur in the form of interpersonal rather than intrapersonal deficiencies. Examples of interpersonal errors may include conveying negative or critical judgment with the result of discouraging patient disclosure of sensitive information, the elicitation of patient defensiveness or shame, or the use of medical terminology in a question that the patient may not understand. Furthermore, errors during history taking may be cumulative. For example, a memory lapse (i.e., intrapersonal skill-based error) may lead to a failure to ask a specific question or failure to probe the full spectrum of patient concerns (i.e., interpersonal communication-based error). The TRACE captures these complexities and allows for a detailed analysis of the human factors that may contribute to insufficient human performance in the data-gathering context of medical care.

4.1.2.2. Errors in diagnosis. Diagnostic error is defined as a diagnosis that is unintentionally delayed, wrong, or missed [25]. Based on a recent analysis of almost 600 reported diagnostic errors in medicine, Schiff et al. found that errors occurred most frequently in the testing phase including failure to order, report or follow-up laboratory results, followed by failures to consider or overweigh competing diagnosis and errors in history-taking or physical exam

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[26]. These type of errors can be considered to occur on both intrapersonal and interpersonal dimensions, although much of the literature categorizes diagnostic failures as primarily cognitive in nature [27].

Even when standard diagnostic practices are followed, misdiagnosis-related harm may occur. As reflected in the first column of the matrix, diagnosis-related complications or accidents may happen due to factors outside of the clinician's control. For example, the clinician may have ordered and monitored appropriate tests, but a technical equipment failure during recording of results may have led to a missed diagnosis (i.e., standard of care adherence with unintended outcome). Alternatively, current diagnostic standards may be unreliable and require revision. These incidents would be considered accidents or complications with potential implications for innovation of diagnostic guidelines (e.g., inherent in the limited success of an existing diagnostic care standard).

When non-standard diagnostic procedures are intentionally initiated and no patient harm is evident, the classification of the action is a close call or possible innovation contingent upon an accurate diagnosis being made that would have been missed with standard procedures, or one that was made in a more efficient and less costly manner than expected from standard procedures. An intended deviation from diagnostic care standards that resulted in harmful misdiagnosis would be classified as negligent medical practice during diagnosis, regardless of factors outside of the clinicians' control.

4.1.2.3. Errors in treatment formulation. Some treatment plans are more appropriate than others because they better capture an optimal balance of anticipated benefits and known risks [21]. However, the benefit-risk calculus is not only based on consistency with care standards as specified in medical guidelines, but also in its accommodation to sociocultural and economic factors that may limit plan appropriateness and acceptability by a particular patient. Such variables include the urgency of treatment, the patient's physical condition (i.e., whether the patient is sick or healthy), philosophic, spiritual and cultural attitudes and preferences (e.g., whether the patient values quality or length of life), as well as treatment cost and patient resources. These factors add a layer of complexity to the treatment formulation that makes the generalizability of practice guidelines more difficult than in other medical contexts.

Taking this limitation into account, there are circumstances in which patient harm might arise despite adherence to medical guidelines in the development of a treatment plan due to factors outside of the clinician's control. For instance, an unexpected change in the patient's physical, emotional, social or financial status may compromise treatment implementation or expose the patient to unanticipated risks. As reflected in the first matrix column, this circumstance would be considered a complication or accident rather than an error since the change in patient status is outside of clinician control. However, along the same lines as discussed in the previous medical contexts, an adverse outcome despite "good practice" may also imply a need to revise current practice guidelines regarding treatment formulation. This illustrates how a utilization of the TRACE despite successful or harmless unintended outcomes may yield valuable information regarding competent intervention strategies with errors-in-the-making.

Evident in the second column of the TRACE matrix are instances when standard treatment planning guidelines are not followed, either intentionally or unintentionally. For example, a physician may go forward with a treatment plan without remembering that an outstanding laboratory test had not been checked, or that a chart note was incomplete or outdated (i.e., intrapersonal lapse). In a similar vein, the physician may misspeak in dictating a chart note or enter an unintelligible order that goes unread or unfilled (e.g., active and latent interpersonal slips). A physician may also intentionally recommend a treatment plan that does not conform to medical standards. If this deviation is forced by external circumstances discussed above (e.g., economic, philosophic, spiritual, or cultural patient factors), the implications of this column change – in this case, the success or failure of the treatment plan is outside of the clinician's control and Banja's reasonability criterion applies in evaluating whether or not the deviation involved a human error. An intentional deviation with a *successful* outcome may imply innovation and suggest a revision of traditional care standards.

Patient-centered communication plays a critical role in the development of an acceptable and appropriate treatment plan. For instance, a treatment plan may be regarded differently in terms of effectiveness and appropriateness by the patient and physician, as might be the case in deciding between palliative or aggressive treatments for a life-threatening condition. Interpersonal errors might include failure to probe and elicit the patient's expectations and preferences, use of medical jargon, and complex language that a patient may not understand to present the nature of the proposed treatment in regard to alternatives, risks, cost and side effects, or affective cues conveying dominance, irritation, rejection or disrespect.

4.1.2.4. Errors during treatment execution and monitoring. Many treatment execution errors are intrapersonal and arise from monitoring failures that include errors of omission (i.e., leaving out an appropriate step in a process), errors of insertion (i.e., adding an inappropriate step to a process), errors of repetition (i.e., inappropriately adding a normally appropriate step to a process), and errors of substitution (i.e., inappropriate object, action, place or time) [28]. In addition to these cognitive lapses, behavioral slips such as a literal slip of a surgical knife or other technical errors in the performance of a procedure, incorrect administration of a medication, or the false adjustment or setting of medical equipment are also common in treatment execution on an intrapersonal performance domain.

There are also a host of interpersonal challenges during treatment execution, including passing on critical information when handing off or delegating responsibility for treatment, or when interacting with team members during surgical procedures. In fact, a large majority of errors that lead to severe critical incidents occur during handover, staff group communication, and teamwork communication [8]. For example, physicians may fail to communicate, miscommunicate, or ambiguously communicate crucial information to the patient or other members of the medical team [29]. In addition, a patient's physical or psychological condition may make verbal communication impractical or impossible, and particularly in moments of crisis, nonverbal communication may be the only way to interact with the patient or medical staff members [30].

As reflected in the first column of the TRACE matrix, there are circumstances in which patient harm might arise during the execution of a medical treatment due to factors outside of the clinician's control (e.g., side effects, allergic reactions, etc.). These instances would be designated as complications if they were a known risk, or as accidents if they occurred due to an unpredictable circumstance. Again, an application of the TRACE could reveal potential errors-in-the-making that were successfully intervened, or suggest potential revisions of current practice guidelines in the case of unintended outcomes.

When non-standard treatment execution strategies are used (i.e., second matrix column), the outcome might result in classification of the action depending on the (non)existence of

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an appropriate implementation guideline as presented in the discussion of treatment planning. If no patient harm resulted, the action may be considered a possible innovation (contingent upon a successful outcome), or a close call. If an adverse event occurred during implementation, the action would be classified as a complication or accident (lacking an applicable practice standard), or as a human error (assuming the existence of an applicable standard) on at least one of the TRACE performance dimensions.

4.1.2.5. Errors during post-treatment follow-up. Follow-up and monitoring of patients after treatment execution is an essential component of competent medical care. This task entails attentional reflection on the original treatment plan, its intentions, and its results. Physicians mostly engage in cognitive evaluations of the extent to which the diagnosis, treatment plan, and treatment execution were successful. If the desired outcome was not achieved, practitioners may have to engage in problem-solving activities to reassess and potentially modify the original diagnosis and treatment plan in an attempt to minimize the discrepancy between the present position and the desired state. Thus, errors that occur during the evaluative phase of the post-execution stage will primarily be intrapersonal in nature. For example, physicians may misapply a well-tried troubleshooting rule to explain and fix an unsuccessful treatment outcome (e.g., rule-based mistake), or they may engage in flawed on-line reasoning because they have no contingency plans or pre-programmed solutions that would account for the specific situation (e.g., knowledge-based mistake) [12].

Interpersonal errors are also evident in the post-treatment context. Physicians' communication to the patient, the patient's family, and/or to ancillary staff may be incomplete, confusing, or poorly timed. For instance, discharge instructions may be given to a patient still groggy from medication and without an available family member present, and may proceed without medication reconciliation or without proper feedback to primary care or other relevant health care providers. These types of errors have been associated with adverse ambulatory medication events and higher rates of re-hospitalization [31]. In the event of the disclosure of bad news (such as a medical error), physicians may provide insufficient information (i.e., hypo-disclose), excessive information (i.e., hyper-disclose), or information that is later found incorrect (i.e., misdisclose) [32]. Furthermore, practitioners may communicate inappropriately in a defensive or inattentive manner because they may lack the motivation, knowledge or skills to conduct the disclosure in a competent way.

As reflected in the TRACE matrix, post-treatment complications or accidents may occur with or without adherence to standard care practices. Because of the lack of guidelines in this particular medical context, a majority of the trial-and-learn experiences captured in the TRACE may eventually lead to guideline construction. The TRACE aids the empirical delineation of such events and thereby contributes a comprehensive understanding and evaluation of human performance in post-treatment medical care.

4.1.3. Assessing feedback loops and compounded errors using the TRACE

The TRACE matrix can be applied to evaluate human performance in various medical contexts. However, a meta-contextual analysis is necessary to identify potential compounded errors. For example, an error during data gathering or diagnosis may be uncovered during formulation of the treatment plan when inconsistencies or contradictions arise. A comprehensive application of the TRACE in each clinical context enables a detailed analysis of these interlinked factors and thereby facilitates a competent defragmentation of complex medical care.

4.2. Practice implications: utilizing the TRACE as a heuristic instrument

The TRACE provides practitioners and health care institutions with the means for a comprehensive, detailed analysis of human performance across the spectrum of five clinical practice contexts. Such an analysis aids the prevention of unnecessary recurrences of critical events, and promotes the development of successful strategies that may facilitate the detection and intervention of errors-in-the-making. The TRACE also facilitates an objective "fact-check" in the midst of the emotionally charged experiences that often overwhelm practitioners in the context of a critical event. It reduces the cognitive distortion that results from affective reactions and thereby facilitates a timely and competent response and/or intervention.

Another significant contribution of the TRACE is its identification of the sometimes close link between error and innovation. It is in this area where science and medicine advance, as the mechanism of success is explicated and replicated through case reports. Important trial-and-learn experiences require informed deviations from medical guidelines and may evidence more effective treatment solutions.

The TRACE can also be used to facilitate a competent prevention of critical events. Its typology of human medical errors allows practitioners and medical institutions to focus their prevention efforts specifically on intrapersonal and interpersonal medical performance dimensions. Thus, the TRACE facilitates the implementation of targeted competence training interventions that advance practitioners' knowledge, motivation and skills in intrapersonal and interpersonal medical activities across the five medical contexts.

4.3. Conclusion

Despite all efforts to detect and correct human errors, they will continue to happen [28]. We suggest that the proposed TRACE matrix may add an empirical foundation to the systematic inquiry regarding critical events, illuminating particular error-prone intrapersonal or interpersonal actions that tend to reoccur in medical practice. Using TRACE as an accurate and efficient data keeping system for this purpose may empirically enhance and support quality improvement efforts.

Appendix A. Using the TRACE to defragment complex critical incidents

Scenario 1: Adherence to medical care standards:

A 45-year-old man was submitted to the orthopedic surgery service ten days ago for a left hip fracture after falling off a ladder. His post-operative recovery was complicated by hyponatremia, thought to be SIADH (Syndrome of Inappropriate Antidiuretic Hormone). He was transferred to the medicine service with postoperative hyponatremia. The patient has a single remote history of a gastrointestinal bleed due to a gastric ulcer.

While examining the patient prior to transfer to the medicine service, the physician notices that the patient's left leg appears swollen and orders a lower extremity duplex scan that reveals a deep venous thrombosis. The physician starts the patient on Lovenox at the standard dose of 1 mg/kg every 12 h. He also orders daily weights and Ins/Outs to manage the patient's fluid/electrolyte status.

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Four days later, the patient has a massive upper GI bleed requiring six units of blood. The patient endured hypertension and mild confusion that potentially could have sent him to the ICU. On reviewing the chart, the physician notices that the patient's admission weight is listed as 160 kg, which seems high for the size of the patient. No weights had been recorded on the medicine service despite his orders, but the physician had also neglected to check the daily weights. The physician finds out that the technicians had transposed this patient's weight for another's. The patient is re-weighted, and his weight is found to be 85 kg, not 160 kg. Based on this faulty admission weight, the patient had been receiving twice as much Lovenox as he needed, which led to his GI bleed.

TRACE analysis:

(1) *Medical standard of care*: Physician adhered to diagnostic and treatment standards.
(2) *Medical outcome*: Adverse event (outcome was not as intended, patient was harmed).
Question: Was the adverse outcome caused by human error(s) or by uncontrollable events?
(3) *Human performance contributed to the critical incident*:
(a) *Intrapersonal performance dimension*:
- Treatment Execution: Active skills (lapse: physician failed to monitor weights); Latent skill (slip: nursing failed to noticed discrepancy between recorded weight and patient's physical appearance).
- Medical History Assessment: Latent skills (slip: technicians transposed false admission weight).

(b) *Interpersonal performance dimension*:
- Active communication error (physician failed to communicate his order effectively).
- Latent communication error (nursing did not question the doctor as to why daily weights and Ins/Outs were not ordered for patient).
Conclusion: The adverse event was caused by several human errors both active and latent and across several clinical contexts.

Scenario 2: Intentional deviation from medical care standards:

A diabetic patient was admitted to the hospital for an acute worsening of COPD. She requires insulin to maintain her blood sugars at acceptable levels. Once she is stable, the admitting physician handwrites an order for the patient to receive "7U" of NPH insulin before supper.

The nurse that cared for the patient transcribed the admission order onto the patient's Medication Administration Record. The nurse relied on the copy of the handwritten orders, but the physician's handwriting was a bit difficult to read. The nurse thought that the "U" was a "Zero," and transcribed onto the MAR sheets "70 units NPH." Using the handwritten orders, the nurse double-checked the insulin dose with another nurse before delivering it. This dose is definitely higher than usual, but the nurse has had patients on this much insulin in the past. In the late evening, the patient is found unresponsive in her room with a blood sugar level of 30 mg/dl. The patient is given IV dextrose, successfully resuscitated, and transferred to the ICU for monitoring overnight. On the next morning, the patient returns to the floor without any apparent lasting adverse effects. The physician was aware that "U" is on the long list of unapproved abbreviations, because it has been shown to result in errors including ones in which it is misinterpreted as a zero. However, the physician has been using the abbreviation for years and never had any problems before.

TRACE analysis:

(1) *Medical care standard*: Physician intentionally deviated from abbreviation standards.
(2) *Medical outcome*: Unintended outcome without harm lasting harm.
Question: Was the unintended outcome caused by human error(s) or by uncontrollable events?
(3) *Human performance that contributed to the critical incident*:
(a) *Intrapersonal performance dimension*:
- Active knowledge (knowledge-based mistake: nurse relied on stored knowledge structures in administering the medication dosage).
- Active motivation (a lack of motivation might have caused the nurse's failure to contact the physician directly).
- Latent knowledge (rule-based mistake: physician applied a bad rule based on his biased stored knowledge structures).
- Latent motivation (no motivation to follow abbreviation standards).

(b) *Interpersonal performance dimension*:
- Active knowledge (rule-based mistake: nurse double-checked the dosage with another nurse but failed to contact the physician directly; workspace limitations may explain is mistake).
- Latent motivation, knowledge and skills (physician failed to communicate his prescription order effectively because he applied a bad abbreviation rule and lacked motivation to adhere to abbreviation standards).
Conclusion: The critical incident was a harmless hit (a number of human errors reached the patient but inflicted no lasting harm).

Scenario 3: Unintentional deviation from medical care standards:

An obese middle-aged male is undergoing elective splenectomy for ITP. Due to a determination of megaspleen, the surgeon chose to perform surgery through an upper midline incision. Multiple laparotomy sponges are utilized to pack the abdomen during splenic mobilization to manage the resultant bleeding. The blood soaked sponges are passed off into a kick bucket, weighed, counted, and bagged periodically throughout the case. The surgical procedure concludes and while technically challenging, appears uncomplicated. As the surgeon and the surgical

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team prepare for closure, the nurses begin the sponge count. They are interrupted by the intercom and a request for the surgeon to scrub out and consult on an emergency case in an adjacent OR theater. The surgeon confers with the residents (who are in the first week of rotation with him) about completing the case and directs them to proceed with the closure. The nurses complete the sponge count. The residents complete the closure, but neglect to perform a final comprehensive exam of the abdomen before they close. The nurses document a correct final count.

During rounds two days after the operation, the patient complains about a vague, persistent abdominal pain and has a low grade fever. An abdominal X-ray shows a foreign body consistent with a retained surgical sponge in the patient's left upper quadrant. A re-operation to remove the retained sponge is indicated.

TRACE analysis:

(1) *Medical standard of care*: Surgeon and nurses adhered to surgical standards.

(2) *Medical outcome*: Adverse event (outcome was not as intended, patient was harmed).
Question: Was the adverse outcome caused by human error(s) or by uncontrollable events?

(3) *Human performance that contributed to the critical incident*:

(a) *Intrapersonal performance dimension*:

- Active knowledge (knowledge-based mistake: residents were unaware that they had to perform a complete abdominal cavity examination prior to closing).
- Active skills (lapse: nurses miscounted the sponges).
- Latent knowledge (intercom interrupted the workplace condition; hospital policy did not routinely enforce post-op radiographs after abdominal surgery).

(b) *Interpersonal performance dimension*:

- Active skills (lapse in a familiar routine: both the surgeon and the scrub nurse forgot to cue the residents to perform a final wound examination).

Conclusion: The adverse event was caused by several intrapersonal and interpersonal human errors.

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