Pitfalls in the Evaluation and Management of the Trauma Patient

Pitfalls are typically concealed dangers or traps to untrained or unsuspecting persons. In the context of medical care, pitfalls are common situations encountered in patient management that may result in the clinician being misled or rendered unaware by lack of unique knowledge (usually of the pitfall), or by unusual presentations. Failure to avoid these traps often results in errors and adverse outcomes. Any discussion of clinical management pitfalls is, almost by definition, a discussion of how we, as fallible human beings, make mistakes. It is also a discussion of the environment we work in, as associated with latent failures in a system of care. Although the focus of this monograph is on individual decision making and potential practitioner-based errors, physicians are increasingly being viewed as 1 element in a more complex system of care. Practitioner errors, in this context, are increasingly being examined not as individual failures but more as manifestations of system-based deficiencies (eg, inadequate training, insufficient backup, hard-to-use equipment, fatigue, and so forth).

The following discussion cannot possibly cover the entire range of possible pitfalls in the management of the trauma patient and is not intended to be encyclopedic in this regard. It does provides an overview of the nature of pitfalls and their relationship to human errors and weaknesses (latent failures) in a system of care, followed by a more detailed review of selected pitfalls that may occur in various phases of trauma care. In doing this, it is hoped that the reader will gain some appreciation of the more important, higher impact errors that may occur and can acquire sufficient insight to avoid many of them.

Vulnerabilities, Threats, and Errors: The System We Work In

Although the focus of this monograph is on individual provider errors, in the final analysis, all providers are part of the greater system of medical, or in this case, trauma care. Pitfalls in the management of the

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TABLE 1. Errors, Pitfalls, and Latent "Failures" Within a Trauma System

Inherent characteristic of trauma system	Latent failure (vulnerability)	Potential outcome, error of pitfall
Unpredictable and intermittent high patient volume and acuity	Transient staff and resource shortages, system incapacity	→ Practitioner errors and system "volume saturation" failures
Need for time-sensitive performance of providers and system as a whole	Inadequate response times, untimely communication	→ Delayed diagnosis and treatment of critical conditions
Long work hours, off-hours, exhausting pace, high-risk patients	Stress and fatigue, diminished performance	→ Practitioner technical and/or management errors
Highest risk injuries occurring infrequently in many centers	Insufficient provider experience and/or knowledge base, stress	→ Practitioner technical and/or management errors
Multi-system injuries with silo-like activity of services by specialty	Poor communication and fragmentation of care	→ Delays in diagnosis/treatment and provider errors
Residency training programs with rotating house staff (learning curve repeated every 1 to 2 months)	Insufficient provider experience, inadequate knowledge and training, inadequate supervision	→ House staff technical and/or management errors
Large service information management demands (many patients, many studies, many details)	Incomplete, untimely, or inaccurate communication of information	→ Practitioner management errors, delayed diagnosis/treatment.
Large potential for clinically occult injuries	Unsuspecting, inexperience, or improperly trained provider	→ Potentially high incidence of delayed or missed diagnoses
Constantly changing resources: technology, personnel, staffing levels, facilities, organizations, regulations, etc.	Staff and resource shortages, insufficient provider experience and knowledge and training	→ All of the above

trauma patient occur not only as a result of perplexing or unusual patient conditions or presentations, but also as a result of inherent vulnerabilities and internal and latent threats existing within the system of care. Medical systems are inherently complex, and the adverse events that arise within them are typically a function of multiple factors. Before one can consider pitfalls, it is important to understand the nature of the system in which those pitfalls occur.

The care and management of the severely injured multiple trauma patient, more than most endeavors in the field of surgery, involves the interaction of a variety of specialists, subspecialists, equipment, and other resources, all within an organized system of care. The infrastructure that a trauma system requires is extensive, involving a continuum of response and care from prehospital activation to long-term management. Communications ("911"), response and transport (eg, fire, paramedics), designated specialized facilities (trauma centers), highly experienced and trained personnel, and an organization that provides oversight are all components of this complex system.[1]

The interactions between various personnel, subspecialists, ancillary staff, and subsystems take place in an environment that is, by nature, very challenging from a patient-safety standpoint, creating a complex system with numerous vulnerabilities (Table 1). Activity levels at major trauma centers are unpredictable, with the potential for bursts of high patient volume and acuity. Providers of trauma care are often faced with the need to make highly time-sensitive decisions, often with limited information. The opportunity for more contemplative evaluation, consultation, or research often does not exist.

The very nature of major life- and limb-threatening injury and the time-sensitivity of management creates a high stakes, high-risk environment which, for many providers, is stress producing. Much of major trauma occurs during off hours, late evenings, and early mornings, requiring optimal performance under even more challenging circumstances. The logistics of providing seamless 24/7 coverage for a wide variety of services may also require expanding the pool of personnel to those with more limited experience, interest, or knowledge of more complex injuries. The various factors may conspire to degrade the safety and reliability of the overall system of care, creating additional latent pitfalls or hazards.

Additional factors, long established in the culture of surgery and surgical training programs may actually run counter to creating a risk-free environment. The surgical "culture of invulnerability" (to stress, fatigue, excessive work hours, and so forth), the balkanization of specialties, and limited opportunities to develop coordinated teamwork, and the sometimes loosely structured nature of supervision in some surgical residency programs are examples.

Recognizing and avoiding pitfalls is an inherent component of patient safety. The goal and challenge, in terms of patient safety, is to devise a system of care within this challenging environment that will increase the redundancy of safety-related measures, improve the resiliency of both the system and its providers to errors, and ultimately improve outcome. The performance of such a system should be provider independent, time-of-day insensitive, and be capable of responding to sudden, unexpected increases in volume and acuity.

Threats and System Failures Contributing to Errors

Errors are intrinsic to humans functioning within a system of care. Increasingly in health care, as in commercial aviation, the patient safety focus is moving away from individual human error and more toward creating resiliency within the overall system of care. The system of medical (or trauma) care is a complex one by any measure, with vulnerability to failure both exacerbated and mitigated by the actions of the providers within it. Some of the features of a complex medical systems have been described by Cook and colleagues[2] (Table 2).

Providers, working within this complex system, will regularly encoun-

TABLE 2. Features of a Complex Medical System

- Complex systems are intrinsically hazardous systems. The complexity of the medical care system, by nature, creates multiple opportunities for system failure. This includes provider errors.
- Complex systems contain multiple defenses against failure. In medical systems, this includes policies, procedures, training, credentialing, and redundancy of care in many areas.
- Practitioners are an important source of resilience and defense against system failures. In many cases, the practitioners are the most adaptable element in complex systems, and constantly work to adapt to system needs and actually prevent adverse events.
- Catastrophic failures within the medical system typically require multiple points of failure. Very much like commercial aviation, an adverse event occurs as a result of multiple, smaller failures within a given system.
- Medical systems contain a constantly changing array of latent failures within them. As the result of these latent failures, complex systems, by definition, run in a degraded mode. In any given time, latent failures, such as staff fatigue, inexperience, difficult to use equipment, etc.
- The expertise and experience of practitioners in a complex system is constantly changing, and this change introduces new forms of system failure.
- Hindsight bias often results in erroneous analyses of adverse events.
- Creating a system with a low incidence of adverse events requires experience with adverse events.

ter threats to system performance that may, in turn, threaten optimal patient outcome. These threats have been categorized into external, internal, and latent. External threats may be thought of as environmental risk factors that are apparent, or at least accessible to the frontline team (the "sharp end"). In the clinical arena, external threats may include patient injuries, broken or unavailable equipment, or lack of available personnel. Internal threats are regarded as those being intrinsic to the team of providers, those at the so-called sharp end of the system domain. Lack of training, lack of competence, fatigue, even animus between team members may all be considered internal threats. Latent threats, originally defined by Reason,[3] are a broad category of threats not always apparent or accessible to the medical care team that act to increase the likelihood of adverse events or errors. Policies, organizational cultures, equipment prone to failure or risky to use in some circumstances, or nonexistent backup systems all might be characterized as latent failures. In those cases, these include a wide variety of situations, conditions, and deficiencies that are difficult to identify until an adverse event has occurred (Table 1).

Most latent system failures and human errors do not result in significant adverse events. This is due, in part, to the fact that most clinical situations are relatively failure insensitive. In trauma, the most patients are either low acuity or exist in situations in which failures and errors will have low

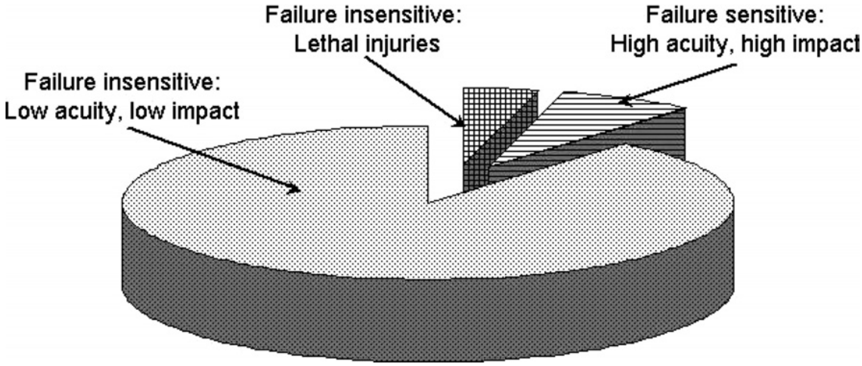

FIG 1. Relatively low percentage of failure-sensitive cases may underexpose system and/or provider vulnerabilities.

impact. At the other end of the acuity spectrum, the most severely injured patients will succumb, regardless of errors or failures (Fig 1). In addition to failure-insensitive cases, additional factors adding to the overall system resiliency, including provider factors, act to prevent adverse events. In a popular model of errors called the "Swiss cheese" model, layers of safeguards or defenses are set up (the slices of "cheese"), all of which have "holes" or defects in them (Fig 2). As the environment spins off threats and creates hazards, adverse events are blocked by these various defense layers. Occasionally, the holes (failures) in the system all line up, creating a confluence of defects leading to an adverse event.

Human (Provider) Errors

A clinical pitfall, for purposes of this discussion, is a recognized situation encountered in the course of treating patients that creates a predictable vulnerability to human error. The key terms here are "recognized" and "predictable," which illustrate that pitfalls are regularly encountered and the erroneous decision making that occurs in response to the vulnerability can be forecast to some degree. Human error has been a subject of great interest to cognitive psychologists for years and more recently has become a focus for the health-care profession as well.[4]

Several schemes for human error have been developed that may be applicable to trauma-based providers and teams. Rasmussen and Jensen[5] described 3 categories of error based on cognitive stage: skill-based (eg, technical errors), rule-based (eg, deviations from guidelines or established practice patterns), and knowledge-based errors. Helmreich and Foushee[6] have described 5 types of errors based on observations conducted in the

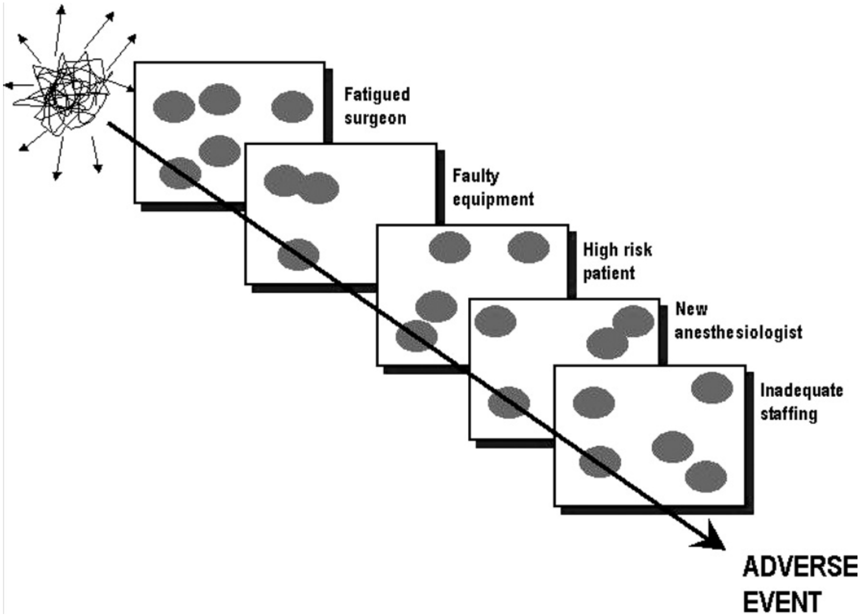

FIG 2. The "Swiss cheese" model for errors. Hazards spun off in a given environment do not produce adverse events unless defects (failures) in the layers of defenses or safeguards occur in concert with each other (the "holes lining up").

TABLE 3. Types of Errors

- Task execution errors: In surgery, this could include technical slips and psychomotor errors (eg, bowel injury during laparotomy), and judgment or perceptual errors causing a technical error such as laparoscopic bile duct injury.
- Procedural errors: Errors involving deviation from existing practice pattern or protocol (eg, failure to administer preoperative antibiotics for a bowel case).
- Communication errors: Communication of incorrect data, failure to communicate important data, delayed communication of critical data, etc.
- Decision errors: Errors in judgment related to patient management.
- Intentional noncompliance.

airline industry that may have application in the study of errors made by surgical practitioners (Table 3).

Of all the error-based events occurring in the care of trauma patients, diagnostic delays and missed injuries are perhaps the most pervasive and often the most serious. These events often involve either the improper selection of information (knowledge-based and decision errors) or the improper processing of that information (rule-based and procedural errors). Based on years of observations, there appear to be 3 more common general

TABLE 4. Common General Errors

- False Attribution: False attribution involves the tendency to incorrectly link a clinical observation with an unrelated cause. This tendency ignores 1 of the basic principles of trauma management: that the level of suspicion, diagnostic evaluation, and initial management should proceed on the basis of assumed worst-reasonable-case scenario. False attribution (of signs or symptoms, laboratory or radiographic findings etc.) may occur for many reasons, but often involves selectivity in the processing of clinical information. The consequences in a severely injured trauma patient may be devastating. Examples include: (1) attributing observed hypotension to a vaso-vagal reaction with the actual cause being hemorrhage; (2) attributing the same hypotension to a malfunctioning automated blood pressure machine; (3) attributing a tender abdomen to the observed abdominal wall contusion when the actual cause is peritonitis.
- False Negative Prediction: This error occurs when an inappropriately strong negative predictive power is attributed incorrectly to a given physical finding, imaging study, or laboratory value. Examples include: (1) the abdomen is benign, so intra-abdominal hemorrhage can be effectively excluded; (2) the heart rate is normal, therefore the patient could not be in hemorrhagic shock; (3) the CT scan is normal and, despite physical findings, the patient could not have a serious intra-abdominal injury. The vast majority of physical findings, laboratory studies, and even many imaging studies have a sensitivity rate that falls below a level that would provide for an appropriate degree of negative predicted value in many of these situations.
- Erroneous Labeling: Diagnostic labeling involves the attachment of a premature or presumptive diagnosis as a "label" for a patient. The trauma team then comes to refer to the patient by this "label" and regard it a definitive diagnosis even if more complete data or diagnostic evaluation is lacking. It is often 1 of the most tempting and potentially 1 of the most hazardous errors made in the initial assessment of the acutely injured patient. Confirmation bias, the inherent reluctance to relinquish a current diagnosis despite the presence of conflicting clinical information, likely plays a role in its development. Diagnostic labeling also may act to curtail more complete diagnostic evaluation and/or intervention. The "stab wound to the arm," for example, is the patient with an obvious, but clinically insignificant upper extremity laceration who, as the result of the "label," has no further diagnoses considered or workup performed, and suffers a delayed diagnosis of a ruptured spleen despite mild abdominal tenderness. The "labeling" acted to distract the clinicians from considering the possibility of blunt as well as penetrating injuries.

errors made in the diagnostic evaluation of trauma patients, even by experienced clinicians. These include what amounts to false attribution, false negative prediction, and erroneous labeling (Table 4). The underlying causes for these thought process errors have their roots in cognitive psychology and are discussed in detail in more comprehensive analyses of human error.[3,7-10]

Mindset and Approach to the Management of the Trauma Patient

By its nature, the practice of providing trauma care to victims of critical injury involves a rapidly changing, dynamic process. Providers are often called on to make important critical clinical decisions with little or

TABLE 5. Guiding Principles

• **Patients should typically be managed according to the worst reasonable case scenario.** generally assuming, or at least being prepared for the worst until proven otherwise. This is particularly true from a diagnostic and monitoring standpoint, taking a liberal approach to imaging studies, and even invasive surgical procedures, when indicated, with the overall goal of minimizing risks to the patient.
• **Listen carefully, but remain a bit skeptical of the history of injury.** Injury scenes are often chaotic and the information available to the prehospital crew frequently incomplete. Falls are not always falls, assaults may involve both blunt and penetrating mechanisms, patients found down in urban environments could have sustained just about anything.
• **Look carefully at the patient.** This sounds simple, but subtle findings are often overlooked on the physical examination and can make critical differences in some situations. The stab wound to the neck obscured by a cervical collar in a blunt assault patient; the ice pick to the areolar margin of the nipple overlooked in a hemodynamically unstable patient; the gunshot wound to the tympanic canal labeled as an assault, or the "found down" with tread marks and massive pelvic fractures are types of incidences that occur in a situation in which the clinical history is inconsistent with the observed injuries.
• **Constantly reassess, never assume "stability."** Providers accustomed to caring for patients in less dynamic environments often assume that what was true 10 minutes ago will continue to be true. There is a tendency, related to cognitive processing, to "wish" patients to do well. This tendency can lead to complacency in the setting of critical and rapidly changing conditions.
• **Trauma is a team sport. Cooperative and maintain collegiality.** The patient suffers when this does not happen. Save confrontation until after the patient is taken care of and use institutional processes and mechanisms, as needed, for conflict resolution.
• **Maintain the "clock speed" for diagnosis and management.** Be aware of the specific time sensitivities for various injuries (eg, limb ischemia), and prioritize accordingly.
• **Never become married to the diagnosis.**
• **Never become married to the sanctity of the operation.** Missed gastrointestinal injuries, anastamotic leaks, recurrent or ongoing hemorrhage, vascular graft occlusions, etc., will occur with infrequent but predictable regularity. Postoperative "denial" is a recognized pitfall, and may be overcome by a more team-approach to patient care.
• **Look for risk reduction strategies and measures in diagnosis monitoring and management.**

minimal amount of diagnostic information in an environment of constantly changing clinical conditions, resources, provider skills, and so forth. The general philosophy regarding the management of trauma patients must be directed at avoiding many of these pitfalls and avoiding errors. Although being somewhat consistent with the old dictum, "assume nothing; trust no one," the general approach to critically injured patients involves several additional guiding principles (Table 5).

Potential Failures in Team Dynamics: Trauma Resuscitations and the Operating Room

The initial evaluation and management of the trauma patient, typically occurring in the emergency department or a similar specialized area of the hospital, involves a multidisciplinary group of providers and ancillary personnel. The size of the resuscitation team will vary from center to center according to the acuity of the patient. In smaller Level 2 and 3 centers, it may include emergency medicine physicians, a trauma surgeon, and a small number of ancillary personnel (eg, nurses, medical technicians, radiology technicians, and so forth). In larger Level 1 centers, the group may be considerably expanded and includes residents from various specialties, anesthesiologists, specialty consultants in orthopedics and neurosurgery, and so forth. In many situations, there will be members of the resuscitation team unfamiliar with the other providers. In teaching environments, there will be a variable and constantly changing skill mix in the team members (eg, residents in structured teaching programs), creating opportunities for errors as the result of latent failure in team dynamics or individual members. Although the team is smaller, similar situations can also exist in the operating room for critical cases.

The management of high risk, high acuity trauma patients requires continuous monitoring of a relatively large number of physiological and laboratory parameters, many of which may change dramatically over a short period of time. As threatening clinical situations develop, often quickly, the awareness and responsiveness on the part of the resuscitation or operative team becomes an important determinant of successful management of these threats and ultimate patient outcome. Much of the work accomplished over the past 20 years in the enhancement of anesthesiology monitoring in the operating room has been directed at increasing this "situational awareness" and improving the response to clinical "threats." Work by Gaba and others[11,12] has resulted in the development of the operating room simulation, using computer-controlled mannequins in a realistic operating room environment, and to directed and improved performance skills in critical situations. This program, called Anesthesia Crisis Resource Management (ACRM), can be used to record, analyze, and ultimately improve individual and operating room team interactions in the operating room.[13,14]

Errors in the resuscitation room or operating room may be the result of a failure in team dynamics, caused not so much by individual medical errors, but by the manner in which team members interact (Table 6). These interactive processes may be, in turn, influenced by other latent factors such as poor room design, risky or failure-prone equipment, or a culture of "never question the surgeon."

The ability of a team to respond to varying internal and external threats, as well as maintain a resiliency to latent failures, has been best studied in the field of commercial aviation, 1 of the 2 high reliability systems in existence. Research by NASA into the causes of commercial airplane

TABLE 6. Examples of Potential Problems (Failures) in Team Dynamics: Trauma Resuscitations and the Operating Room

Error in patient management due to incomplete information (failure to maintain situational awareness)	
Incomplete history or physical examination [resuscitation]	
Inadequate patient physiological monitoring (eg, arterial, CVP lines) [resuscitation, OR]	
Inadequate patient laboratory monitoring (eg, coagulation parameters, hematocrit, base deficit, ABGs) [resuscitation, OR]	
Failure to recognize ongoing blood loss [resuscitation, OR]	
Failure to recognize worsening hypothermia, acidosis, or coagulopathy [OR]	
Failure to maintain uninterrupted supply of blood and blood products [OR]	
Errors in communication	
Clinical findings clear to team [resuscitation team leader]	
Overall management plan [resuscitation team leader]	
Expectations, danger points of anticipated procedure [resuscitation, OR]	
Significant changes in patientÆs physiological status (hypotension, hypoxia etc.) [resuscitation, OR]	
Unexpected operative blood loss [OR surgeon]	
Unavailability of instrument or equipment [OR nursing]	
Procedural maneuvers with the potential to provoke physiological alterations (eg, compression of vena cava, cross-clamping of aorta) [OR surgeon]	
Errors in workload distribution	
Inexperienced and poorly oriented staff (eg, medical students in major resuscitation)	
Staffing deficiencies: resuscitation, OR, multiple disciplines	
Insufficiently experienced or trained house staff or attending staff conducting difficult procedure [OR]	
Surgical or anesthesiology staff distracted or pulled away due to other trauma patients	
Lack of adequate supervision of house staff	
Conflict resolution issues	
Unresolved hostility due to perceived inadequate performance by other team member(s)	
Disagreement regarding scope of responsibility and team leadership	
Disagreement regarding overall management plans or conduct of a procedure	

CVP, central venous pressure; ABG, arterial blood gas; OR, operating room.

crashes in the late 1970s revealed that many pilot errors were not the result of individual failures, but the result of breakdown in leadership, crew communication, and teamwork. This research led to more intensive examinations of airline crew dynamics and resulted in the development of training processes that emphasized optimizing interpersonal and functional interactions in a response to potential threatening situations. Cockpit Resource Management (CRM) training has since undergone significant modification and revision. In a more recent iteration of CRM, termed Threat & Error Crew Resource Management, the training recognizes the inevitability of some degree of human error and attempts to trap and minimize the results of these errors.[15] This program reflects the recognition that crew interactions and teamwork training are critical elements in managing situational crises.

There are additional challenges to team dynamics in medical environments, however. In commercial aviation, a pilot and copilot both have access to similar situational monitors, possess similar skills and training, were trained in a highly disciplined culture (often the military), and are tasked with controlling a device of human design that obeys well-understood physical laws. Members of a trauma team, on the other hand, may include emergency medicine physicians, surgeons, anesthesiologists, and other specialists, each with different skills, training, and expertise, and often with access to different clinical information. They are tasked with responding to the needs of the human organism, an entity that is only partially understood and seemingly defies the known physical and biological laws that might apply to it. Each team member may be unaware of significant developments in the absence of near continuous, high fidelity communication, and each may respond differently to various situational threats. Communication of physiological status, airway management, critical laboratory values, and radiological studies, and interacting effectively to manage threats posed or suggested by this information, is critical to the outcome of the patient.

Optimal behavior in the setting of major resuscitations and critical operative procedures has not been defined for medical teams, but several specific behavioral markers have been identified in the study of commercial aviation that are seen to help mitigate threats and errors. Some of these behavioral markers, adapted to a medical context, are shown in Table 7**.** Many of these may have applicability both in the operating room and in the resuscitation room.[16]

Pitfalls During Initial Evaluation and Resuscitation

Resuscitation Team Organization and Function

The importance of team dynamics in the resuscitation area and the operating room has been discussed previously. Several specific aspects of resuscitation team interactions and common errors are worth additional focus (Table 8).

Although there is no formulaic solution to reducing risks and pitfalls in the resuscitation arena, a couple of approaches to improving both knowledge and the effectiveness of team interactions may be considered. Trauma resuscitation videotaping has been used for many years to improve both knowledge and organization during resuscitations.[17-19] The growth of these techniques has been impeded somewhat by confidentiality and privacy concerns, but properly structured programs for trauma videotaping have been developed that are consistent with both the Joint

TABLE 7. Behavioral Markers for Team Function in Medical Environments

BRIEFING	The required briefing was interactive and operationally thorough	*Concise, not rushed, and met standard of practice Bottom lines were established*
PLANS STATED	Operational plans and decisions were communicated and acknowledged	*Shared understanding about plans: "Everybody on the same page"*
WORKLOAD ASSIGNMENT	Roles and responsibilities were defined for normal and non-normal situations	*Workload assignments were communicated and acknowledged*
CONTINGENCY MANAGEMENT	Team members developed effective strategies to manage threats to safety	*Threats and their consequences were anticipated Used all available resources to manage threats*
MONITOR/CROSS-CHECK	Team members actively monitored and cross-checked patient status and team status	*Patient and team status were verified*
WORKLOAD MANAGEMENT	Operational tasks were prioritized and properly managed to handle primary patient care responsibilities	*Avoided task fixation Did not allow work overload*
VIGILANCE	Team members remained alert of the environment and status of the patient	*Team members maintained situational awareness*
AUTOMATION MANAGEMENT	Information and other technologies were properly managed to balance workload requirements	*Equipment setup was briefed to other member Effective recovery techniques from equipment anomalies*
EVALUATION OF PLANS	Existing plans were reviewed and modified when necessary	*Team decisions and actions were openly analyzed to ensure the existing plan was the best plan*
INQUIRY	Team members asked questions to investigate and/or clarify current plans of action	*Team members not afraid to express a lack of knowledge - "Nothing taken for granted" attitude*
ASSERTIVENESS	Team members stated critical information and/or solutions with appropriate persistence	*Team members spoke up without hesitation*
COMMUNICATION ENVIRONMENT	Environment for open communication was established and maintained	*Good cross talk; flow of information was fluid, clear, and direct*
LEADERSHIP	Team leader/surgeon showed leadership and coordinated resuscitation/operative deck activities	*In command, decisive, and encouraged team participation*

Adapted from Helmreich RL, Musson DM, Sexton JB. Human Factors and Safety in Surgery. In: Manuel BM, Nora PF, editors. Surgical Patient Safety: Essential Information for Surgeons in TodayÆs Environment. 1st ed. Chicago: American College of Surgeons; 2004.

Commission requirements and those of the Health Insurance Portability and Accountability Act (HIPAA).

More recently, the use of simulation has been extended to both procedural and organizational aspects of medical teams and trauma resuscitations.[20,21] Although it is too early to assess the overall effectiveness of this approach on actual patient outcomes, both knowledge and skill acquisition appear to benefit.

Trauma Team Activation and the Prehospital Report

The trauma team, depending on location, size, and type of center, is composed of various individuals, but typically includes emergency medicine, general surgery, ancillary staffing with nursing and medical technician support, radiology, sometimes anesthesiology, and others. Standards for trauma center performance require a rapid response from the trauma team to ensure that it is in place at or before patient arrival.[22]

TABLE 8. Common Resuscitation Errors

- Failure to identify the team leader and to establish the subordinate roles of other resuscitation team members. This may be particularly difficult to do in academic teaching environments where other team members may be more senior or experienced.
- Usurpation of team leadership, typically by a more senior team member, may lead to confusion, redundant or conflicting instructions, and general confusion.
- Failure of team members to be assertive in 2 areas: (1) making the team aware of changes in a patient's condition, or critical diagnostic findings, and (2) making the team leader aware of incipient errors.
- Failure of the team leader to communicate not only instructions, but the overall plan and direction for the resuscitation, and to be receptive to input from other team members.
- Failure to establish appropriate monitoring and frequently reassess the patient. This is strongly related to the concept of "lack of situational awareness."
- Failure to identify situational threats including risky behaviors, questionable or incorrect decisions, inexperienced personnel, etc.
- Failure to identify the high risk patient and institute risk-reduction measures. There is a tendency to standardize treatment and monitoring for a given (current) condition as opposed to utilize preventive risk-reduction strategies, individualized to a given patient.
- Failure of adequate supervision: this is often a problem in teaching programs where less experienced personnel are dependent on proper supervision and assistance by more senior personnel.
- Crowd control: trauma resuscitations can sometimes look like television shows and often everyone wants to get involved. Volunteers, social workers, medical students, and patients' families all have roles to play, and these roles must be prioritized in the context of life-saving interventions in the patient's critical illness.

Trauma team "activation" depends on high fidelity communication, appropriate (accurate) field assessment by prehospital personnel, and a sufficiently sensitive activation "trigger" based on reasonably standard physiological, anatomical, and mechanistic criteria.[23] As might be expected, systems relying on these many elements are prone to intermittent failure. Problems created by this include late activation response of the trauma team, associated delays in diagnosis and treatment, missed communication, inappropriate higher or lower level of response, and preparation for adult (versus pediatric) victims. In addition, for critical resuscitations, delayed activation or response of the surgical team can lead to subsequent failures of communication associated with the need to "catch up" on problems identified in decisions already made.

In urban settings with a higher volume of penetrating trauma, the timeliness of trauma team activation and response is critical. Failed or delayed activations in this setting can have an important impact on outcome. An important latent failure in many trauma centers is the lack of redundant systems for trauma team activation, using cellular communication, short-wave radio, or hospital-wide audio paging systems. In addition to problems with failure or delayed activations, many systems lack the capability for the transmittance of detailed patient-related prehospital information to members of the now-activated trauma team. The provider and institutional responses to trauma team activation for a hypotensive patients suffering from abdominal gunshot wounds (who will likely require an immediate operating room and possibly massive transfusion) is different from the response to a 5-year-old unconscious victim after a fall (who will likely have pediatric airway management needs and require a computed tomographic [CT] scan and possibly neurosurgical intervention). More detailed information transmitted from the prehospital providers to the larger trauma team (including the operating room, blood bank, and neurosurgical services), allows for a better prepared, better tailored response.

Airway Issues

Airway management is at the top of the priority list in any major trauma resuscitation, and errors in airway management can lead to some of the more serious catastrophes in the early care of the patient. In any trauma system, airway management begins in the prehospital arena and is carried through to extubation and even intensive care unit (ICU) discharge. Common problems are summarized in Table 9.

In selecting the airway device to be used, it should be kept in mind that formal tracheostomy tubes were designed for just that, a formal tracheostomy, and not necessarily designed to be placed within the more rigid structure of the cricothyroid channel. Hypoxia, cricothyroid damage, or both have been associated with wasted attempts to pass larger or more rigid formal tracheostomy tubes in this emergency situation and dependence on these tubes creates a latent failure. Taking the "keep it simple, stupid" approach and using a #6 (or relatively small) cuffed endotracheal tube substitutes a flexible, more easily inserted tube, providing more than adequate airway for temporary ventilation in these critical situations.

Failure to Recognize Hemorrhagic Shock

As simple as it sounds, failure to recognize hemorrhagic shock is 1 of the more common and more lethal pitfalls seen during initial resuscitation. Although every individual in the trauma bay has an appreciation for the importance and critical nature of hemorrhagic shock, an early presentation of normotension may create the illusion of what is referred to using the dreadful term "hemodynamic stability," ignoring that a 30% to 35% circulating blood volume loss may be sustained before the onset of hypotension. The formal classification of patients into hemodynamic categories defined in *Advanced Trauma Life Support*[30] (eg, responders,

TABLE 9. Common Problems in Airway Management

• Unrecognized prehospital esophageal intubations: Esophageal intubations continue to occur at a rate reported between less than 0.5% to more than 6%.[24] They often occur in the setting of difficult airways and/or severely injured patients. Other tube misplacements occur with some regularity, including supraglottic and right main-stem placements, but the impact to the patient is typically less with these errors. The large number of prehospital providers relative to the ongoing experience in endotracheal tube placement creates the latent failure in this setting, and may be offset by a program of frequent simulation drills in airway management skills and/or one-on-one airway management instruction in the operating room by anesthesiologists. The increasing use of either colorimetric carbon dioxide detection (less reliable) or continuous infrared capnography (more reliable) in the prehospital arena has also reduced the number of problems in this area.[25]
• The emergency department airway "flail": Obese, short neck, direct airway or neck injuries, aberrant anatomy, the inability to flex the neck (potential cervical spine injury) all may conspire to create extraordinarily challenging impediments to the placement of an endotracheal tube. Failures in this setting include those similar to the general resuscitation: failure to identify threats and recognize errors, and poor communication. It is imperative in these situations that the provider charged with the responsibility for airway management (typically emergency medicine or anesthesiology) work closely with the surgeon in the event that a surgical airway is required. Techniques for "rescue" ventilation should be well defined and may include the use of combi-tubes or laryngeal mask airways.[26-28] The use of these situations for "teaching opportunities" for less experienced personnel is to be avoided, if not condemned. The criticality of the situation demands that the most experienced individual be tasked with the airway management.
• The "best" surgical airway: With the increased use of percutaneous dilatational tracheostomy in the ICU and improvement in equipment, the percutaneous cricothyroidotomy, using the Seldinger approach, has become increasingly popular. Against this background, many surgeons remain most comfortable with surgical cricothyroidotomy and oftentimes these 2 available technologies result in conflicts. Conflicts result in errors and errors result in adverse outcomes. During the most time-sensitive intervention performed in the trauma arena, time is wasted in confused discussion regarding "better" technique must be avoided, and issues regarding technique should be worked out well beforehand. Cadaveric studies are somewhat variable, but may suggest that in nonsurgical hands, the percutaneous approach has some advantages.[29] As a general rule, however, the level of relative experience should dictate the technical approach.

transient responders, nonresponders) may help avoid early misclassification and labeling. A trauma team may be lulled into believing that response to volume resuscitation with elevation of blood pressure, albeit transient, represents the cessation of hemorrhage, or at least the cessation of shock, ignoring the more pressing reality.

Most providers can recognize decompensated shock, often referred to as "hemodynamic instability." Class III hemorrhagic shock, the state in which 30% to 40% of an individual's blood volume has been lost, creates a persistent decrease in systolic blood pressure. At this point, the body's compensatory mechanisms, including adrenergically mediated vasocon-

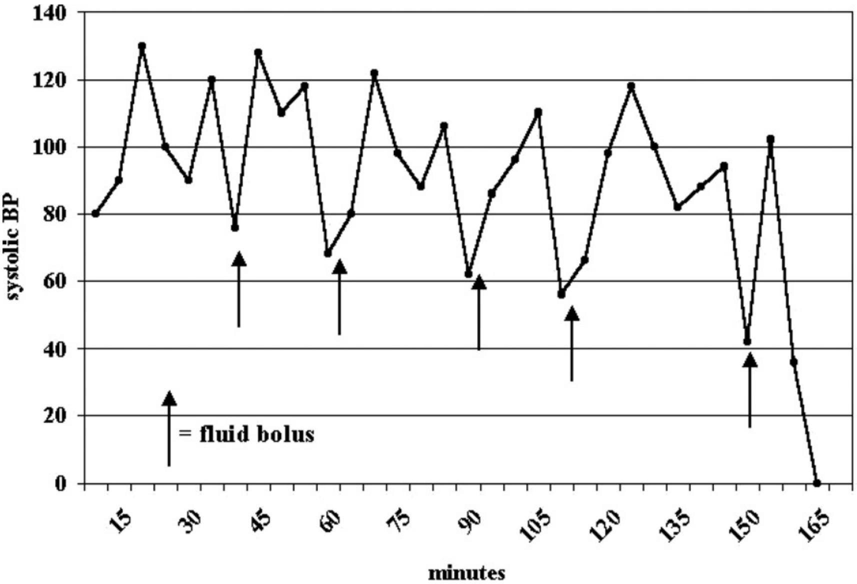

FIG 3. Intermittent hypotension in the setting of ongoing hemorrhage and recurrent volume resuscitation. Despite the intermittent return of "normal" systolic blood pressure, the patient remains in a prolonged shock state, which, if not definitively corrected, will result in the patient's demise.

striction, release of stress hormones, and fluid shifts into the intravascular space, fail to sustain adequate perfusion to vital organs. This is most commonly appreciated on a clinical level by decreased urine output and changes in mental status.

Errors most commonly occur when there is some element of compensated shock, a state in which the patient's physiologic ability to vasoconstrict masks blood pressure changes in the setting of significant hypovolemia, or in the setting of transient response to volume resuscitation. The saw-tooth blood pressure pattern of recurring normotension and hypotension often reflects ongoing hemorrhage in the setting of intermittent fluid resuscitation. It results from a patient in hemorrhagic shock who had received intermittent bolus fluid administration (intermittent peaks) while actively hemorrhaging (subsequent recurrent valleys) (Fig 3). The error made is the assumption that each fluid bolus returns the patient to a state of normal physiology when, in fact, the overall shock state and acidosis is worsening. Patient tolerance of this situation is limited and will depend on the age of the patient and the rate of ongoing blood loss. Eventually, the ability to compensate is overwhelmed, and the progressive ischemia and acidosis triggers myocardial compromise and further decreases in cardiac output to the point of irreversibility.

Two other errors associated with delayed diagnosis of shock occur intermittently. The first is the association of the "talking patient" with an acceptable physiological condition, or the absence of a shock state. The second relates to the failure, on the part of the clinical team, to modify the threshold for "normotension" in a trauma setting.

The misinterpretation of normal mental status as a sign of stability may be a particular problem in the young adult patient who may be awake and alert in a setting of profoundly decompensated shock and a low systolic blood pressure. Often the low blood pressure is attributed to failure of the cuff device in a false attribution error. In reality, an otherwise healthy patient with an intact mechanism of cerebral autoregulation may have the capacity to maintain near normal cerebral perfusion without major alterations in mental status until they "crash." Even when combative behavior is present, it may be mislabeled as the result of head injury or drugs rather than a sign of a severe shock state.

Other errors in recognizing a shock state are made in patients for whom a standard scale of normotension may not apply, particularly in the very young and very old. The elderly patient with a blood pressure of 120/70 (who is normally hypertensive with a pressure of 180/100) may be in a decompensated shock state. Similarly a hypotensive child may be erroneously regarded as having an "age-appropriate" blood pressure, ignoring other physical findings of a shock state.

Failure to Properly Assess the Abdomen and Pelvis

The abdomen often represents a "black box" with respect to early diagnosis, and failure to appropriately evaluate the abdomen has been identified as the most common error in trauma management.[31,32] The abdominal examination is notoriously unreliable in the trauma patient, but depending on the level of stability of the patient, the correct and reliable diagnostic modality can usually be identified. The most serious errors occur when the potential for major abdominal injury is overlooked altogether.

The clear strategy to reduce the rate of missed injuries to the abdomen starts with obtaining an accurate history of the event, either from the patient or a witness. Information of a witnessed blunt assault with concomitant penetrating trauma is invaluable and should raise suspicion for injury. Furthermore, if there is any suspicion for injury, additional diagnostic studies should be obtained. In the patient without evidence of serious shock, or who responds well to fluid resuscitation (responder), multislice CT scan is usually the appropriate choice. In the patient with decompensated shock who fails to respond or transiently responds, other modalities such as focused abdominal sonography for trauma (FAST) or diagnostic peritoneal lavage (DPL) should be considered. Most radiology departments are poorly equipped to run major, ongoing trauma resuscitations, and preventable deaths have occurred as the result of attempts and completing abdominal CT scans in patients with decompensated shock whose resuscitation is further compromised by the location in the CT suite.

FAST examination and DPL are well-founded techniques in the evaluation for abdominal injury in the unstable patient. The choice is largely operator dependent. In skilled hands, FAST can detect approximately 200 mL of fluid in the peritoneal cavity. Subtle hollow viscous injury with little spillage will be missed by this technique alone. The accuracy for detecting significant pericardial fluid is high, typically greater than 95%. For hemoperitoneum, the sensitivity is 80% to 95% depending on the study conducted.[33] Inaccurate screening examinations can have morbid consequences. Factors influencing inaccuracy of the FAST examination include improper technique, inexperienced operator, and inappropriate use. These factors must be considered given the stakes in a hypotensive patient.

Both FAST and DPL have been used in the setting of hemodynamically normal patients, but their utility in this setting, when a multislice CT scan is available, has been questioned and may lead to delays in definitive diagnosis. A literature review recently conducted by Griffin and Pullinger found little data to support the use of FAST examination to reduce the use of CT scanning.[34] Some authors have suggested that the use of DPL as a screening examination along with complimentary CT scanning is more cost effective and may lead to a low nontherapeutic laparotomy rate.[35,36] If CT scan is not readily available, for example, in a mass casualty situation, this may be a viable strategy.

The use of FAST for blunt abdominal trauma is well validated, but the extended use of FAST for penetrating trauma creates risk due to its inability to detect small amounts of intra-abdominal fluid associated with hollow viscous injuries. In a single institutional study, the sensitivity of FAST was found to be 46% and the specificity 94%. As this issue goes to press, there is a multi-institutional study being conducted by the Western Trauma Association to examine the use of FAST in patients with stab wounds. Great caution should be exercised with FAST in this setting, particularly if hollow viscous injury is suspected, until further data are analyzed.

DPL is known to have a low specificity rate and high sensitivity rate, with the sensitivity being the source of greatest error, particularly in blunt trauma where the majority of patients with hemoperitoneum resulting from more minor solid organ injuries (eg, liver, spleen) may be treated without operative intervention. The sensitivity for DPL in the setting of penetrating trauma may be adjusted by the red blood cell (RBC) count threshold. The risk-reduction tradeoffs are an increased sensitivity with lower thresholds (<10-15,000 cell/cu.mm.) and a somewhat higher nontherapeutic laparotomy rate, versus a higher incidence of missed injuries or delayed diagnoses associated with the lower-sensitivity, higher RBC thresholds (>25,000/mm^3)[37]

Slow or Incomplete Response to the "Bad" Pelvic Fracture

Hemorrhage is the most frequent cause of death associated with pelvic fractures, making the more severe pelvic injuries extremely high-risk situations. Errors in management typically occur in 2 varieties: delayed recognition in the severity of hemorrhage, or the pursuit of an incorrect treatment strategy. An additional risk factor often present in these patients is advanced age. The massive hemorrhage often associated with these injuries creates secondary problems of coagulopathy and hypothermia, making prophylactic interventions the most effective. Methods for hemorrhage control include direct operative control (rarely needed outside of major vascular injury), indirect operative control through the use of packing, pelvic external fixation, and arteriography and embolization for arterial hemorrhage. Patients often will not tolerate therapeutic or "strategic" management errors and the use of these modalities must be timely and appropriately sequenced.

Risk factors for major hemorrhage include physiological status on arrival, the number and type (greater with posterior injuries) of fractures, age of the patient, and associated injuries. The early detection of hemorrhage amenable to angio/embolization is possible through the use of helical CT scanning of the abdomen and pelvis, showing evidence of active arterial extravasation from the pelvic vessels. Recognition of pelvic extravasation has been shown to be a reliable predictor of arterial pelvic bleeding and the need for angiographic embolization.[38,39] Delay in diagnosis and treatment of arterial pelvic bleeding places the patient at risk for multiple transfusion and its sequelae, including death. Bleeding sources in the pelvis may also include the venous sacral plexus as well as cancellous bone, and the utilization of fracture fixation may be an important adjunct in these patients.

TABLE 10. Protocols for Patients with Pelvic Fractures

- Pelvic binders for external compression. These act to reduce the displace fracture and improve compliance characteristics of the pelvic "bowl" for subsequent embolization.[42]
- Massive transfusions protocol (MTP).
- Anesthesiology involvement. These cases are similar to major operative cases and should be run accordingly.
- Hypothermia precautions and the use of active warming devices (eg, Bair Hugger)
- Preload and arterial monitoring. Central venous lines and arterial lines should be used liberally.
- Procoagluants (rFVIIa, rFIX for patients receiving coumadin). Although proper execution of an MTP will help prevent coagulopathy, patient may benefit from the administration of additional factors.

Given the multidisciplinary, multimodality needs of the major pelvic fracture patient, it is not surprising that the most frequent errors are organizational, and most accessible opportunities for improvement exist in crafting a scripted, organized approach to management. Recent reports suggest significant outcomes benefit to the use of practice management guidelines.[40,41] Protocols are tailored to prevent known risks (Table 10).

Physiological Traps in Special Populations

Avoiding pitfalls in the pediatric trauma population is largely dependent on being properly prepared. An effective system of preparedness may involve, for example, the use of color-coded resuscitation drawers based on the size of the child and the Broselow Pediatric Resuscitation tape. Special attention must be given to the room temperature, as small children are particularly susceptible to hypothermia. Incorporating pediatric service providers into the trauma team is important, particularly for very young patients.

The elderly trauma patient warrants special consideration and a fair amount of caution. Hemodynamic considerations are particularly noteworthy. Medications such as beta blockers and calcium channel blockers can blunt the normal tachycardic response associated with many traumatic events. In addition, physiologic derangements of the normal chronotropic response, as well as pacemakers, may also lead to erroneous assumptions about the (normal) state of a patient's hemodynamics. A normal heart rate is a poor indicator of the absence of a shock state, in general, and may be particularly misleading in an elderly patient.

The elderly patient is also particularly susceptible to noncavitary hemorrhage, due to the relative loss of connective tissue integrity, and to the loss of the normal ability to tamponade soft tissue hemorrhage. The presence of calcified and easily sheared vessels contributes to the

TABLE 11. Potential Pitfalls in the Management of the Elderly Patient

What the injured elderly might tell you (if they could)	The reason for this and potential pitfall
"I can go from normotensive to hypotensive in a heartbeat."	Profound, life-threatening hypovolemia may occur in the setting of relatively normal BP. Physiological reserve is minimal and hemodynamic decompensation can occur quickly.
"I respond poorly to too much or too little fluid."	The therapeutic window for cardiac preload is narrow and inadequate preload monitoring may lead to errors in volume resuscitation.
"My subdural hematoma hasn't expanded enough yet to really affect my level of consciousness."	Cortical atrophy, common in the elderly, may act to delay the clinical manifestations of serious intracranial hemorrhage. This hemorrhage may be clinically occult.
"Trauma is not really my major problem."	Stroke, myocardial infarction, seizures may result in falls or motor vehicle crashes and delayed diagnosis of the principal underlying problem.
"I only look like I have adequate ventilatory reserve."	Ventilatory failure and respiratory arrest may occur suddenly in conjunction with chest or abdominal injuries despite a relatively benign outward clinical appearance.
"I get demand ischemia if I have too much pain or my hematocrit drops below 29."	Myocardial (demand) ischemia may result from severe or prolonged pain or transfusion thresholds that have not been appropriately liberalized in the setting of coronary artery disease.
"I can't stand even a little shock or hypoxia. . . and neither can my myocardium."	Even minor perturbations in perfusion, oxygenation, or vasoconstriction may lead to major cardiac complications.
"My connective tissue just ain't what it used to be.. . ."	Decrease in connective tissue integrity with less tamponade effect for hemorrhage into soft tissues. Blood loss into soft tissue spaces, including subcutaneous loss, may be excessive and is often overlooked.
"The sensitivity of my abdominal exam is better than flipping a coin. . .but not much."	Clinical manifestations of serious abdominal injury in elderly patients are often minimal. Reliance on the abdominal examination will often lead to missed abdominal injuries.
"My bones are brittle. . .my hip bone, my shin bone, and my aortic bone!"	Blunt aortic injury may occur in the elderly in the absence of conventional signs or symptoms. A low threshold for CT imaging should exist.
"A little medication goes a long way with me.. . ."	Failure to adjust medication dosage, particularly sedative-hypnotics and analgesics may result in serious complications.
"I just haven't been eating so well lately."	Chronic malnutrition is relatively common and often undiagnosed.
"My injuries weren't accidental."	Elder abuse is relatively common and often unreported and undiagnosed.
"Major trauma? Heck, I wouldn't even tolerate a brisk haircut.. . ."	Underestimating and undermanaging comorbidities (COPD, coronary artery disease, smoking, etoh, etc) may result in preventable morbidity/mortality.

BP, blood pressure; CT, computed tomography; COPD, chronic obstructive pulmonary disease.

potential for occult bleeding within subcutaneous, retroperitoneal, or intramuscular spaces. A list of important considerations in the elderly population appears in Table 11.

The pregnant patient may also present some very unique pitfalls, and every female trauma patient who may be of childbearing age should have a urine pregnancy test sent as part of the initial resuscitation. Failure to recognize pregnancy early leads to serious delays in diagnosis as well as avoidable radiation exposure. Obstetrics consultation should be sought for all pregnant patients.

Most pitfalls and errors in the setting of managing the pregnant patient stem from lack of familiarity or a protocolized approach to management. Risk reduction is directed at preventing fetal hemorrhage or hypoxia from placental injuries, and well as diagnosing direct fetal injury. The key steps to initial evaluation should involve an assessment of abnormal fetal heart rate/rhythm, the presence of contractions, any vaginal bleeding, ruptured amniotic membranes, or a distended perineum. The threshold for continuous fetal monitoring should be low. An assessment of fetomaternal hemorrhage using the Kleihauer-Betke test may provide a sensitive indicator of placental injury and guide treatment to avoid sensitization in Rh-negative gravidas.

It is occasionally forgotten that the management of the pregnant patient involves the balanced management of 2 patients. Imbalances in the approach create separate risks; too much emphasis on fetal management may result in maternal complications ("treat the mother to treat the fetus"). Conversely, in situations where C-section delivery is necessary (beyond 26 weeks' gestation), the potential for direct injury to the fetus-now-newborn may be overlooked in the setting of major maternal injuries.

Pitfalls in the Performance of Procedures

Most major trauma resuscitations will involve the performance of invasive procedures. The impact of complications from these bedside procedures, however, is related to the old dictum that "there is no such thing as a small procedure." Risks of resuscitation procedures exist for both high- and low-volume centers, but for different reasons. The risks for high-volume centers (mostly academic Level 1 centers) are related to the relative inexperience of the trainees in teaching programs. The risks for low-volume centers (community or rural Level III-IV centers) may be related to the paucity of ongoing experience by the providers staffing those centers. Most technical mishaps arise in situations in which the external threats and gaps in defenses begin to line up, with high risk patients (eg, extreme obesity, uncooperativeness), high criticality of injury, and need for multiple interventions to proceed simultaneously. In teaching programs, the need for watchful senior supervision cannot be overstated. At lower volume centers, both surgical and emergency medicine providers are increasingly afforded the opportunity to improve or maintain their procedural skills using through coursework such as advanced trauma life support (ATLS) or through specific simulation skills training using models specifically adapted to individual procedures.[43]

Infectious complications are often the most serious and often the most easily prevented procedure-related problems. Many times these complications, which stem from a lack of adequate sterile precautions and aseptic technique, derive from the assumption that a small incision size or a percutaneous procedure is associated with less risk. Quite the opposite is true. Empyema with lung entrapement requiring thoracotomy/decortication and prolonged hospitalization, septic thrombophlebitis or septic venous embolus, and arterial injuries with subsequent hemorrhage or pseudoaneurysm requiring operative repair are but a few examples of how "simple bedside procedures" can be associated with major complications (Table 12). In most cases, strict adherence to aseptic technique, attention to smaller but important details of procedural interventions, and assurance that providers who perform these procedures are either technically proficient or well supervised will result in avoidance of most of these procedural pitfalls.

Operative Pitfalls

The operating room remains the focus for the most critical interventions in the severely injured trauma patient, with the most time-sensitive injuries definitively treated in the operating room. These include massive hemorrhage, expanding intracranial hematomas, limb ischemia, and others. Opportunities for management errors, technical and otherwise, are enormous, and the physiologic tolerance of some patients renders them unforgiving of even minor deviations from optimal care. The challenge of the most severe injuries poses a problem analogous to the old game of "Beat the Clock." The "clock," in this case, may be a combination of time, acidemic load, blood loss, and the duration of the shock state. Beating the clock means controlling hemorrhage, minimizing the physiologic impact of shock, decompressing the injured brain (eg, craniotomy/craniectomy and evaculation of clot), relieving compressed heart (eg, tamponade), and restoration of blood flow to an extremity or organ, and doing this within the limits of patient physiological tolerance. Success is measured in survival and the extent of adverse sequalae following injury. The script for the intraoperative choreography for major trauma is often complex and involves the collaborative expertise of difference disciplines. The simple act of prioritization (eg, airway/hypoxia > massive hemorrhage > cranial decompression > limb ischemia > gastrointestinal contamination) is oftentimes not so simple and can make a critical difference in outcome. The following discussion of operative pitfalls is not encyclopedic by any means, but represents some of the more frequently encountered opportunities for improvement. The focus is on general/trauma surgical operative intervention, but should not be cause to ignore the critical importance of subspecialty operations, particularly neurosurgical interventions in overall management.

TABLE 12. Technical Pitfalls and Complications in Trauma Resuscitation Procedures

Procedure	Threat, Pitfall, Error, or Complication
Chest tubes	
Misplacement	Inexperienced personnel, poor supervision, incision size too small, failure to confirm chest entry by palpation, excessive force and other psychomotor errors.
Infection/empyema	Poor antiseptic preparation, inadequate patient draping, inadequate analgesia or local anesthesia, chest tube manipulation, use of same incision for chest tube replacement.
Lung, liver, spleen injury	Failure to establish landmarks. Failure to palpate pleural space prior to tube placement, inexperience, lack of competence.
Intercostal injury	Failure to incise or dissect above the rib, excessive force.
Pain	Failure to administer appropriate analgesia and local anesthesia. Poor understanding of anatomic structures.
Occulsion	Misplacement (kinking) of chest tube. Failure to use appropriate tube size, failure to "milk" tubes with high blood volume output.
Groin lines and CVP lines	
Venous injury	Back wall perforations related to inadequate skin incision size (loss of sensitivity to increased use of force).
Arterial injury	Failure to palpate artery, failure to assess back-bleeding, inappropriate puncture location (typically too low), poor understanding of anatomic relationships.
False passage	Failure to assess bleed-back, excessive force, inadequate skin incision size.
Infection	Poor or lack of antiseptic preparation, poor aseptic technique.
Pneumothorax (SC,IJ)	Improper patient placement in Trendelenburg position, improper puncture site, excessive force.
DPL	
Bowel, bladder injury	Failure to distinguish between bowel and peritoneum (open procedures), use of DPL at old laparotomy site (adhesions), failure to decompress stomach or bladder, excessive force.
False passage	Fascial incision site too small (increased sliding resistance), failure to elevate fascia on trochar insertion (semi-open procedures).
Infection	Poor or lack of antiseptic preparation, poor aseptic technique, occult bowel injury.
Needle thoracostomy	
Ineffective	Needle/catheter too small. Failure to dislodge fat plug, improper location, catheter or needle too short for location.
Injury to vessels, heart	Inappropriate location of puncture site, failure to establish proper landmarks
Unresolved pneumothorax	Failure to place chest tube following needle thoracostomy.
Resuscitation thoracotomy	
Poor exposure	Failure to extend incision or create "trap door" by dividing medial costal cartilage. Inadequate retractors.
Injury to phrenic nerve	Inappropriate pericardiotomy incision (anterior-posterior versus superior-inferior).
Injury to heart	Technical error in pericardiotomy with epicardial laceration. Digital injury to atria during manual cardiac compression.
Injury to lung hilum	Failure to take down inferior pulmonary ligament, clamp injury to pulmonary vessels during cross-clamping.
Needle sticks and blood/ fluids exposure (providers)	Failure to take appropriate body-substance isolation precautions (eg, masks, hats, eye protection, gloves, gowns). Failure to handle and dispose of sharps properly, inexperienced or inadequately trained personnel, failure of crowd control, cramped resuscitation space.

CVP, central venous pressure; SC, subclavian; IJ, internal jugular; DPL, diagnostic peritoneal lavage.

Beat the Clock: Strategies in the Setting of Massive Hemorrhage

Two principal challenges present themselves in the setting of massive hemorrhage: definitive control and managing the physiological effects of shock. The reversal of the shock state begins during initial resuscitation and its management is directly related to hemorrhage control. In the setting of major (operative) cavitary hemorrhage, the reflex administration of intravascular volume, typically consisting of predominantly crystalloid solutions, may be ill advised. Although the immediate restoration of blood pressure is a tempting target, there is some evidence that this approach may be associated with exacerbation of hemorrhage, thought to be due to a combination of "popping the clot" from higher vascular pressures, and hemodilution.[44] In carefully selected settings, a resuscitation allowing a mild degree of hypotension ("permissive") conducted until definitive intraoperative vascular control is obtained.

In managing the effects of massive hemorrhage and shock, the 3 components of the so-called physiologic vortex (eg, coagulopathy, hypothermia, acidosis) must be considered. Coagulopathy is often the most treacherous, and its management requires the reversal of the shock state and the coordinated use of blood factors, procoagulants, and curtailment of prolonged operative procedures (damage control).

Initial Operative Maneuvers in the Initial Control of Hemorrhage Operative intervention in the setting of massive, life-threatening hemorrhage is a highly dynamic process. Few endeavors in the field of surgery are as time sensitive, pressure ridden, or filled with uncertainty and unpredictability. Many of the pitfalls in this situation are obvious. Operating too slow, proceeding too methodically without the flexibility to adjust the operative approach according to physiologic and anatomic needs, becoming distracted with a single injury, losing focus on prioritization, or proceeding with definitive repairs despite ongoing hemorrhage are all potential pitfalls. While management in each case must be individualized, the sequence of operative maneuvers in the "crash" laparotomy are summarized in Table 13.

Performing these types of maneuvers quickly, effectively, and in the right order is never a guarantee of patient survival. Pre- or intraoperative cardiac arrest resulting from profound shock in the setting of massive intra-abdominal hemorrhage, even if initially resuscitated, results in survival in only a select minority of patients. The survivability depends largely on the rapidity with which hemorrhage can be controlled and the effectiveness of the physiological management.

TABLE 13. Operative Maneuvers in "Crash" Laparotomy

- Expeditious, full-length laparotomy (1 minute).
- Consider temporary aortic occlusion at the diaphragmatic hiatus in highly unstable patients if thoracotomy has not been performed (<1 minute).
- Manual assessment of shattered destructive injuries to the liver or spleen with temporary packing (30 seconds). The undirected, placement of mass, four-quadrant abdominal packs is often ineffective and may use valuable time.
- Immediate assessment of possible retroperitoneal major vascular injuries (eg, aorta, vena cava, iliacs, etc). Mobilization of the left or right organ block to assess this as needed (<1-2 minutes)
- Temporary control of any identified major vascular injuries with clamps (Satinsky), vascular clamps, Allis clamps for vena cava, bulldogs, sponge-sticks, etc.
- Rapid evaluation for any secondary major sources of hemorrhage (eg, major mesenteric, renal, pelvic, etc).
- Reassessment of the adequacy of control of previously identified sources of hemorrhage. Repacking of liver or pelvis, the "30 second" splenectomy, replacement or readjustment of vascular clamps may be necessary.
- Reassessment of the patient's physiologic status, status of blood/factor availability and status of physiologic vortex (eg, temperature, acidosis, coagulopathy).
- Definitive suture control of any secondary significant sources of hemorrhage not amenable to temporary clamp control (eg, mesenteric bleeding).
- Clamp or stapler control of any source of major gastrointestinal contamination.
- Washout and reassessment of the operative site looking for other more minor sources of ongoing hemorrhage.
- Definitive repair, shunting, or ligation of previously identified major vascular injuries, depending on criticality of injury, time required, and patient status.
- Resection and/or temporary closure of any gastrointestinal injuries.
- Rapid and more complete exploration of the abdomen and retroperitoneum and assessment of other potential injuries.
- Assessment, in collaboration with anesthesiology, regarding the need for timing of damage control and premature conclusion of the case with temporary open abdomen closure.
- Reassessment of adequacy of hepatic packing, consider suture control, if inadequate, consider angiography if inadequate.

Unfortunately, the opportunities to practice and perfect operative skills, such as those required in the maneuvers outlined above, are limited in most trauma practices, even in higher volume centers. This creates a situation in which limited experience, often regarded as a latent failure, exists for the most critical operations. Risk reduction strategies addressing this latent deficiency include the use of additional, more senior, experienced surgical help, and the use of operative skills courses specifically designed to increase surgical experience and improve surgical skills in these situations. Examples of this include the Advanced Trauma Operative Management (ATOM) course, originated by Jacobs and colleagues,[45] and the definitive surgical trauma care and definitive surgical trauma skills courses originated by the internationalization for trauma and surgical critical care, and the Royal Colleges of Surgeons.[46]

Errors in Managing the Effects of Massive Hemorrhage A focus on managing the effects of massive hemorrhage must continue before, during, and after the definitive control of hemorrhage. The complex needs of managing ongoing resuscitation, coagulopathy, hypothermia, and a variety of interoperative crises that typically occur in this setting falls to the anesthesiology team. Although it is tempting to believe that the day will be won or lost on the basis of the surgical control of hemorrhage, the effects of a magnificent operative procedure may be lost against the background of inadequate resuscitation or poor control of coagulopathy. Conversely, a variety of surgical delays or technical difficulties in obtaining definitive hemorrhage control may be ameliorated by optimal resuscitation and management of the effects of massive hemorrhage. Most errors and pitfalls in this setting concern the physiological and metabolic management of the patient: suboptimal volume resuscitation with progressive acidosis and hemodynamic failure, inadequate control of coagulopathy or hypothermia, and failure to respond to other causes of intraoperative hypoxia and hypotension.

Hemorrhagic shock results largely from preload deficits, and the failure to adequately monitor preload will compromise resuscitation. For most purposes, the use of arterial and central venous lines will suffice. More recently, experience with the use of transesophageal echocardiography (TEE) to assess preload status suggests that this is a promising modality.[47,48]

Metabolic monitors for ongoing resuscitation include serial arterial base deficit measurements as well as serum lactate measurements. The experience with these measures is considerable, and most reports suggest that they are useful to assess the severity of shock state and adequacy of resuscitation, and as indicators of other nonhemorrhage related hemodynamic derangements.[49,50]

The causes of coagulopathy in the setting of severe injury and massive hemorrhage are complex, but include shock and reperfusion, clotting factor in platelet human dilution, and in some cases the elaboration of tissue factor tissue thromboplastin with its anticoagulant properties. The most common pitfalls in the management of coagulopathy include the delayed recognition that many of these patients present to the resuscitation area with an established coagulopathy before the administration of any significant amount of blood or blood products or fluids. In addition, the delayed response to the needs of a massively transfused patient, or the lack of massive transfusion protocol, may compromise ultimate management.

The recognition that a significant interruption in the flow of blood and blood products during massive transfusion can mean the difference between life and death has led to the widespread development and implementation of massive transfusion protocols (MTPs) in major trauma centers.[51-53] Efforts should be directed at preventing shock, anemia, hemodilution, and coagulopathy with an attempt to keep plasma clotting factor activity above the 40% level, based on coagulation studies, and platelets between at least 50 to 100 $\times$ 10^9/L. MTPs vary from center to center. Most MTPs rely on a fixed ratio of packed red blood cells (PRBCs) to plasma and platelets (often in the range of 4 to 6 units of fresh frozen plasma [FFP] per 4 to 8 units of PRBCs). In a review of MTPs, Malone and colleagues[52] proposed a simple 1:1:1 ratio of PRBCs/FFP/platelets (nonapheresis), and there is increasingly a belief that a more prophylactic approach to the massive transfusion patient, using higher ratios of factors/PRBCs, may be of benefit.

In addition to augmented blood factor replacement for massive transfusion, the availability of specific procoagulants may be useful in reversing coagulopathy in some settings. Recombinant factor VIIa is a trypsin-like serine protease that forms a complex with tissue factor at exposed sites of injuries and can induce hemostasis by binding to activated platelets and inducing a localized thrombin burst. It is enjoying increasing off-label use in cardiac transplant surgery and more recently for the coagulopathic bleeding in trauma patients.[54,55] In addition to recombinant factor VIIa (rFVIIa), prothrombin complex concentrates (PCC) are a family of agents consisting of lyophilized concentrates of vitamin K-dependent factors (II, VII, IX, and X). PCC has its greatest utility in the almost immediate reversal of warfarin-induced coagulopathy. It has the advantage of being administered in a low-volume solution without the necessity of and delay of thawing, and can be stored, reconstituted, and administered by the hospital pharmacy (versus blood bank) or potentially in the emergency department. Several small series reports demonstrated clinical efficacy in the very rapid reversal of the International Normalized Ratio (INR), some within 10 minutes, and a good clinical response.[56] PCC, although expensive, is thought to be effective enough to warrant incorporation into several organizational guidelines for the rapid reversal of coumadin-induced coagulopathy in at-risk patients.[57]

Hypothermia, currently under intense investigation for its potential benefits in isolated head injury, has been correlated with higher mortality and derangements of the coagulation cascade in the multi-trauma patient. There is now evidence to suggest that it plays a significant role in left ventricular dysfunction, even if less severe (32-35°C). Although hypothermia begins at the time of the traumatic event, it is often exacerbated during the early phases of resuscitation. Exposure in the field and during transport may contribute to a rapid drop in body temperature, especially in an individual in shock. The fully unclothed patient in the trauma bay may take another thermal "hit," further exacerbated by the rapid infusion of cold crystalloid and blood products.

At each phase of care, there are threats in not preventing or reversing hypothermia. Core temperature monitoring (with thermistor-tipped central lines or Foley catheters) is essential, and active external rewarming with warm-air blankets (eg, Bair Hugger), warmed humidified airway gasses, and fluid warmers will be effective in most cases.

In addition to the medical management of hypovolemia, acidosis, hypothermia, and coagulopathy, the surgical approach of damage control, involving the termination of the operative procedure before the definitive repair of many injuries, may be a life-saving strategy if applied properly.[58-60] Most damage control procedures involve abdominal injuries and the temporary control of gastrointestinal injuries, hepatic packing, and pack or wound vacuum control of the open abdominal wound are common accompaniments. The philosophy and technical approach of damage control is not limited to the abdominal cavity, and may also be applied to selected vascular and thoracic injuries. For vascular injuries, simple ligation with delayed reconstruction, or use of temporary arterial shunts, should be considered in circumstances where the prolongation of the procedure for definitive repair may compromise the patient's ultimate chance of survival. Iliac, femoral, and popliteal injuries are amenable to temporary shunting, if necessary. Axillary subclavian arterial injuries can often be ligated without significant threat to the affected limb due to the rich scapular collateral. In most cases, venous injuries can be ligated. The use of temporary venous shunts, may be considered in some circumstances to improve the overall vascularity in lower extremity injuries.

Thoracic damage control is used with considerably less frequency, but should be considered also in carefully selected circumstances. Destructive injuries of the chest wall in the setting of profound coagulopathy may occasionally necessitate packing, and some patients may not tolerate closure of the chest or mediastinum from a physiologic standpoint, requiring temporary and partial closure.

Delayed Response to Intraoperative Crises: Hypotension and Hypoxia
The critical importance of achieving an optimal resuscitation "trajectory"

and minimizing the degree of malperfusion (shock) in the course of operative resuscitation and intervention has been emphasized previously. Under ideal circumstances, the cause of malperfusion (usually hemorrhage) is brought under operative control during which time resuscitation endpoints are met and the shock state is corrected. There are, however, several occasions when patients fall off this optimal trajectory and either fail to resuscitate properly or experience sudden recurrence of a shock state. The potential causes, although often confined to ongoing hemorrhage, are numerous (Table 14), and proper management requires close collaboration between the anesthesiology and surgical teams.

Tension pneumothorax may be precipitated by positive pressure ventilation in an otherwise occult pneumothorax, and heralded by abrupt increases in ventilatory pressures or decreases in ventilatory volumes, drops in oxygen saturation, hypotension, and so forth. In a fully draped patient undergoing an abdominal procedure, establishing the diagnosis is not as straightforward as might be expected. For the surgical team, however, a quick inspection of the diaphragm is a reliable and very fast diagnostic step.

Nonsurgical site occult hemorrhage from chest, abdominal, pelvic, extremity wound sites, or even scalp lacerations may alone be sufficient to cause recurrent hypotension, which should prompt a rapid diagnostic evaluation rather than assuming a surgical site cause (beware of false attribution). In the setting of massive hemorrhage and transfusion, hypotension is most often related to preload deficits and decreased cardiac output. The assumption, however, by an anesthesiology team that ongoing operative blood loss is the cause will lead to errors and missed or delayed diagnoses on a regular basis.

In addition to hypotension, patients occasionally develop sudden hypoxia. The potential causes are numerous and include occult pneumothorax as well as tension pneumothorax (Table 14), hypoxia caused by exacerbation of a severe pulmonary contusion, typically caused by volume overload, transfusion-associated lung injury (TRALI), air embolism from an unsuspected source such as open (large) venous line, and endobronchial hemorrhage caused by major pulmonary injury and an adjacent open bronchus.

Avoiding Trouble with Hemorrhage and Leaks

The heterogeneity of traumatic injuries is such that the management of each case must be tailored to the overall status of the patient, associated injuries, and the anatomy and severity of the particular injury. Having noted this, the majority of difficulties and pitfalls in the intraoperative

TABLE 14. Causes and Management of Intraoperative Hypotension

Etiology	Diagnosis/management
Unanticipated tension pneumothorax	Communication between surgeon and anesthesiologist. High peak airway pressures + hypoxia → immediate intraoperative inspection of the diaphragm (usually ballooning). Needle thoracostomy (surgeon) followed by formal tube thoracostomy.
Massive hemorrhage, known source	Damage control, packing, wait for restoration of perfusion, blood + blood products. Unnecessary and/or premature inspection of the site of hemorrhage will worsen the situation.
Occult hemorrhage: chest, abdomen, pelvis, extremities, scalp	Frequent reevaluation of chest tube output during other procedures. Intraoperative CXR. FAST or DPL for abdominal source, repeat physical examination.
Air embolism: in association with lung injury or major venous injury	Reduce ventilatory pressures if pulmonary source is suspected. Immediate occlusion of open venous injury for venous source, thoracotomy for cardiac arrest with hilar cross-clamping (pulmonary source), open massage and ventricular venting.
Post-tamponade myocardial failure (stunned myocardium) or progressive postshock cardiac failure	Continuous preload monitoring, avoidance of ventricular overdistension, judicious use of inotropes, and minimal use of α agonists.
Blunt myocardial injury (contusion, tamponade)	ECHO (FAST or TEE), pericardial window for tamponade. Inotropic support, manage concomitant pulmonary contusion.
Iatrogenic vena caval obstruction or occlusion	Surgical team must discuss with anesthesiology team plans for release of occlusion/obstruction, etc.
Progressive brain/brainstem injury or massive cerebral edema at craniotomy	Gradual or staged durotomy during craniotomy. Adequate preload replacement, minimal anesthetic, pressors to support BP. Consider abbreviation of thoracic or abdominal procedure.

CXR, chest radiograph; FAST, focused abdominal sonography for trauma.

environment deal with either poor control of hemorrhage or gastrointestinal leakage. In the former case, it has become recognized increasingly that hemorrhage from less accessible vascular structures, although historically amenable to surgical control, is better treated by arteriography and embolization (Table 15). In the latter case, risk reduction strategies may be appropriate to minimize the opportunities for anastomotic leaks and to control the leakage of other gastrointestinal contents such as bile and pancreatic juice. These risk reduction strategies may include the avoidance of high-risk anastomoses (colo-colostomy in the setting of massive hemorrhage and damage control), fecal diversion, and hand-sewn versus stapled anastomoses.[61] In some cases, the increased use of damage control approach coupled with an open abdomen and the application of

TABLE 15. Selected "Least Favorite" Injuries, Problems, and Management Suggestions

	Major problem and pitfall	Suggestions
Hemorrhage		
"Bad" liver injury (include porta)	Poor control of hemorrhage	Pringle maneuver, ligation of right. hepatic artery (uncommon), repacking, portal vein ligation (see text), arteriography and embolization.
Vertebral artery lacerations	Poor control of hemorrhage	Packing (Surgicel), arteriography and embolization or balloon occlusion.
Subclavian artery/vein laceration	Poor control of hemorrhage	Temporary control with Foley ballon occlusion, control of adjacent collaterals, clavicular osteotomy, thoracotomy for very proximal control.
"Bad" axillary and groin injuries	Unexpected massive hemorrhage, difficult to control	Wide exposure, MTP, tourniquet occlusion of limb (temporary), arterial outflow occlusion.
Deep pelvic GSW with hemorrhage	Persistent hemorrhage	Packing, arteriography, and embolization.
IVC injury	Persistent hemorrhage, difficult to control	Individual control of adjacent venous branches (eg, lumbar, renal, etc.), Allis clamp temporary control, repair of posterior wall through anterior defect.
Retrohepatic IVC injury with caudate lobe and portal vein transection	Prolonged attempts in a futile situation.	There are just some injuries that cannot be repaired (yet).
Leaks		
Head of pancreas	Possible main pancreatic duct injury	Temporize with drains. Study with ERCP and stent as needed. Drain thoroughly. Resection only if other methods fail.
Shredded duodenum	Tissue loss prevents primary repairùpotential for leak	Augment duodenum with Roux-Y small bowel loop and anastomosis.
Complex colorectal injuries	Potential for leaks	Avoid colon anastomosis in high-risk, damage-control situations. Identify all rectal injuries and divert when significant doubt.
GI anastomosis in open abdomen	Potential for leak	Avoid exposure of anastomosis. Avoid colon anastomoses if possible, diversion.

GSW, gunshot wound; IVC, inferior vena cava; GI, gastrointestinal; ERCP, endoscopic retrograde cholangiopancreatography.

the wound vacuum device may augment control of wayward gastrointestinal leakage and actually help control peritoneal contamination.

The global pitfall, in the more difficult to manage traumatic injury, often involves a failure to consider overall risk and implement the appropriate risk reduction strategy.

Pitfalls in Thoracic Trauma: Tamponade, Air Embolism, and Hemorrhage

The early resuscitation environment often creates a potential diagnostic trap in the setting of cardiac tamponade.[62] Caused predominately by penetrating chest trauma, cardiac tamponade often responds to relatively small volume resuscitation, leading to the erroneous conclusion that mild hypovolemia is the underlying cause of the hypotension. During fluid resuscitation for cardiac tamponade, a small to moderate volume bolus will increase atrial filling and, by increasing central venous pressure, restore end-diastolic volumes and systolic blood pressure (Fig 4). This

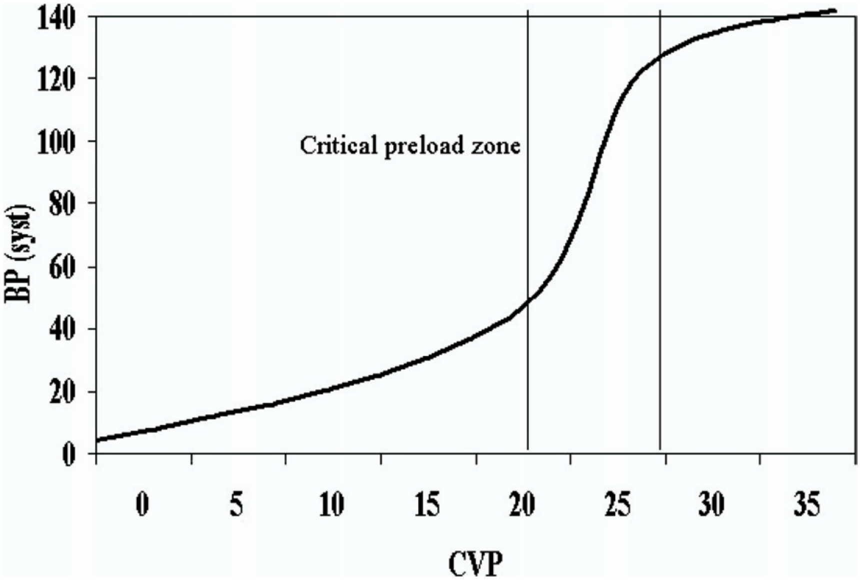

FIG 4. The critical preload zone in cardiac tamponade where small changes in preload, reflected by central venous pressure (CVP), may result in large changes in systolic blood pressure (BP). As tamponade progresses, the curve flattens and is shifted to the right. The curve provides a snapshot in time that might be seen in early tamponade. Over time, the entire curve becomes rightward shifted and ultimately begins to show a decreased BP at any given CVP.

rapid, but temporary, restoration of ventricular filling and blood pressure may lead to the incorrect assumption that the shock state of the patient is due primarily to hemorrhage.

Clinical threats to deriving an early diagnosis include failure to remove the cervical collar to examine for distended neck veins, failure to perform a FAST examination looking for pericardial blood in all patients in shock, or lack of central venous monitoring in the early phase of resuscitation. In addition, the chest radiograph is usually normal, without any signs of pericardial enlargement, creating an additional opportunity for false negative prediction using this absence of enlargement as a means of excluding tamponade.

The threats of sudden hemodynamic decompensation, as illustrated in Fig 4, remain intact until pericardial decompression. Although many patients remain normotensive or mildly hypotensive once the diagnosis of pericardial tamponade is made, the time to decompression should be limited to minutes. Tamponade is essentially a compartment syndrome of the heart and progressive myocardial ischemia can be assumed.

In the same way that tamponade patients respond to small increases in preload, they may also decompensate, even to the point of cardiac arrest, with equally small decreases in preload. This physiologically precarious situation creates a potential trap: on rapid sequence induction, positive pressure ventilation, and increased intrathoracic pressure, preload is suddenly and correspondingly decreased. If the surgical team is unprepared (meaning scrubbed, ready to go, with the patient prepped and draped before induction), there may be a significant delay in immediate pericardial decompression, the results of which may be disastrous.

Although the surgical management of cardiac tamponade is usually straightforward, albeit occasionally difficult, the postdecompression management is not. Two of the most common serious errors made following decompression of tense pericardial tamponade are volume overload with ventricular distention, and the overuse of inotropes, vasopressors, or both. Tamponade cases, with hypotension responding to volume, often have a resuscitative "momentum" associated with them, engendering large volume replacement despite what is often a modest blood loss. Following pericardial decompression, and in the setting of an ischemic, recovering myocardium, excessive volume replacement will result in ventricular overdistention and loss of contractile function. If overdistention is not immediately corrected, myocardial failure and death may result. Normally the pericardium, which is highly nondistensible in the acute setting, acts to protect the ventricles from overdistention. This mechanism is lost following pericardial decompression, creating another potential threat. Cardiac failure tends to recover quickly following tamponade release, and IV fluids should be considerably restrained.

Another common error made in the post-tamponade setting is the continued administration of high dose inotropes (eg, epinephrine). These agents, if used indiscriminately, increase myocardial oxygen consumption, and may precipitate eventual cardiac failure in the recovering post-tamponade myocardium. Modest doses of continuous inotropic support may be necessary to augment the contractile function transiently, but spontaneous recovery of contractile function will typically occur over a short period of time, allowing a fairly rapid taper of inotropic support. The concept of myocardial stunning (postischemic contractile dysfunction) has been well developed in the setting of coronary artery disease,[63,64] and the same pathophysiology may play a role in the post-tamponade patient.

Another, perhaps less frequent trap with thoracic trauma is the precipitation of air embolism, causing sudden hypotension or even arrest.[65] Although more commonly associated with penetrating chest trauma, whereby a fistula is created between the injured bronchiole and adjacent pulmonary vein, air embolism has also been associated with injuries to large abdominal veins (vena cava or hepatic veins), with entrained air migrating to the right heart. Air embolism can be fatal with only 0.5 to 1 mL of gas to the coronary arteries or 2 mL to the cerebral circulation, and often responds very poorly to conventional resuscitative efforts. With both penetrating and blunt chest trauma, air embolism may be precipitated by induction of large tidal volumes during positive pressure ventilation when the pressure gradient shifts in the direction of the pulmonary venous system. This is particularly true of a hypovolemic patient. The clinical presentation may be one of sudden, unexplained cardiac decompensation or arrest. The actual diagnosis often goes unrecognized. Preventive strategies include pharmacological paralysis (to prevent the patient from undesirable coughing), generous volume resuscitation, and the use of lower ventilatory pressures and volumes and the avoidance of overvigorous "bagging."

Treatment involves the immediate repositioning of the patient into the Trendelenburg position with the injured lung dependent to the atrium, acting to increase venous pressure and reduce the gradient.[66] Surgical maneuvers may be necessary in the setting of major lung injury with immediate thoracotomy, hilar cross-clamping for control of the embolic source, ventricular venting to remove entrapped air, and open cardiac massage, as needed.

Pitfalls in Extremity Vascular Trauma

The most critical first step in managing extremity trauma is the physical examination, and this is often incomplete or inaccurate. "Hard signs" for vascular injury including active hemorrhage—expanding hematoma, absent distal pulses, bruit or thrill, or distal ischemia—will usually prompt operative intervention or at least additional diagnostic studies. However, pitfalls occur when proper physical examination is not conducted or when only "soft" signs (proximity of a penetrating wound, small hematoma, adjacent nerve involvement, or an equivocal examination) are present. Missed injuries most frequently occur in these situations.

Obtaining an ankle-brachial index (ABI) or a brachial-brachial index at the bedside in a patient with soft signs is straightforward and provides excellent screening for most significant vascular trauma.[67] An ABI of less than 0.9 has an accuracy of 95%. Another marker that indicates vascular compression is a systolic pressure in the injured limb that is 10 to 20 mm Hg less than in the uninjured limb. It is critical that persistently abnormal

ABIs be followed up within 6 hours of injury with arteriography and appropriate management.

The overriding priority in the management of extremity vascular trauma is minimizing the time to revascularization. Preventable ischemic neuropathy or ischemic myonecrosis can begin to occur within 6 hours from the time of original injury in some cases. Delays in revascularization may occur for a variety of reasons including delays in diagnosis, and prioritizing the management of an associated orthopedic injury over reestablishing perfusion.

One of the more common pitfalls in the management of extremity vascular injury, particularly for those surgeons with less experience in this area, involves an overreliance on formal arteriography in the diagnosis of what, on the basis of physical examination, is a well-localized vascular injury mandating operative exploration. In most centers, formal arteriography can add to hours or more to operative delay, and this can make the difference between a completely viable extremity, and 1 suffering from ischemic neuropathy or even muscle loss. In most cases, particularly involving the lower extremity, on-table arteriography can be performed and provide equivalent information in a much shorter timeframe.

Additional delay in reestablishing blood flow to a nonperfused extremity may be incurred by the desire to establish mechanical stabilization of a fracture adjacent to an arterial injury. Disruption of a fresh vascular anastomosis in the course of open reduction and internal fixation of an associated fracture has been known to occur and is a legitimate concern. In the setting in which there is demonstrable perfusion to the distal extremity, internal or external fixation preceding the vascular repair may be appropriate. In a completely devascularized extremity, delay in reestablishing flow to perform orthopedic fixation may result in preventable ischemia and necrosis. The solution to this particular dilemma involves the use of temporary shunts, placed by the trauma or vascular surgeon, which act to temporarily reestablish blood flow to the extremity while being relatively durable in the setting of orthopedic fracture manipulation. The definitive anastamosis can be performed subsequently at the conclusion of the orthopedic procedure.

The reestablishment of blood flow in a temporarily ischemic extremity is often associated with fairly extensive muscle and soft tissue swelling related to reperfusion edema. The degree to which this occurs is largely a function of the degree of ischemia and the degree of obstruction to venous outflow associated with the original injury. The potential pitfall in this case is the failure to recognize that reperfusion edema, which can precipitate intramuscular compartment syndrome, often occurs in a delayed manner.

Mature judgment is essential in the decision about whether or not to perform fasciotomies in patients in this clinical setting. Indications for compartment decompression include any intraoperative signs of compartment syndrome, including elevated compartment pressures exceeding 25 mm Hg, or postoperative signs or symptoms of compartment syndrome.[68] A 4-compartment fasciotomy of the lower extremity is the standard of care. Although generally a straightforward procedure, the deep posterior compartment must be approached through the superficial compartment and is notorious for being missed during compartment decompression. Muscle infarction and rhabdomyolysis may result.

The Intraoperative Missed Injury

Trauma surgery is perhaps 1 of the few areas of surgical endeavor where the preoperative diagnosis is often not known. The term "exploration" is often applied to surgical procedures (exploratory laparotomy, thoracotomy, wound exploration, and so forth) and, in the true sense of the word, means to investigate or examine systematically. Unfortunately, even systematic explorations or investigations can miss certain types of injuries. Occasionally these misses are operator dependent, but often they're the result of misleading visual or tactile clues, erroneous assumptions made about relative lack of findings, or misperceptions regarding how a gunshot or knife trajectory might be capable of creating certain injuries. Several pitfalls in this area have been identified.

In the abdomen. Missed small bowel injuries may occur by overlooking tiny lacerations or even small mesenteric hematomas associated with an obscured lacerations. Failure to explore these thoroughly, including taking down adjacent peritoneum and even dividing the small adjacent mesenteric vessels may result in missed injuries. In the colon, contusions and serosal tears should not be treated lightly particularly in the cecum and right colon. Delayed tissue breakdown from contusion-related local devascularization may result in late performation and a conservative approach to imbrication is recommended. The inability to visualize the colon due to lack of mobilization has also been associated with missed injuries. A complete mobilization, particularly with penetrating injuries, should be performed in cases in which there is any suspicion whatsoever.

Blunt and penetrating pancreatic injuries may present the surgeon with the problem of evaluating the main pancreatic duct, and delayed diagnoses may occur. While on table transmitting all endoscopic, retrograde, cholangio-pancreatography (ERCP) is discouraged, postoperative ERCP with or without the placement of a transpancreatic duct stent is useful in detecting these injuries.

In the liver, deeper, partial arterial injuries may be missed in the setting of stab or gunshot wounds, producing pseudoaneurysms and delayed bleeding. Postoperative follow-up CT angiography of the liver will usually suffice to identify these relatively uncommon lesions, and arteriographic embolization usually constitutes definitive management.

In the rectum, an inability to visualize the rectal mucosa due to stool in the vault may obscure an injury, and often these are too deep in the pelvis to be explored from a transabdominal route. Rigid sigmoidoscopy may occasionally miss injuries, some of which may be palpable on digital examination. Flexible endoscopy, although still operator dependent, may provide a more thorough evaluation.

In the chest. Missed injuries in the chest are relatively uncommon. Exploratory thoracotomies are typically predicated on hemorrhage and probably the most common cause of missed significant hemorrhagic lesion in the chest is intercostal injuries due to either penetrating trauma or occasional focal blunt trauma with lacerations to the intercostal vessels. At thoracotomy, these vessels may either not be visualized due to the location of the incision or may actually be compressed by the use of self-retaining retractors placed in the chest wall. In patients requiring thoracotomy for hemorrhage, these misses are almost always associated with "red herrings" such as associated minor lung lacerations. When any suspicion exists, careful examination of the chest wall, even occasionally requiring the use of dental mirrors, should be undertaken.

In the neck. Vascular injuries are uncommonly missed and typically result from lack of thorough exploration. Vertebral artery injuries may be difficult to explore and suspicion should prompt postoperative arteriography. In addition, injuries to the esophagus may occasionally be missed and suspicion should prompt concomitant esophagoscopy.

In the retroperitoneum. Ureteral injuries occur mostly from penetrating injuries, and may be associated with minimal retroperitoneal blood, leading the unsuspecting surgeon to conclude that no injury is possible. Thorough exploration of stab wound or gunshot wound trajectories when they lie proximal to the ureter should be undertaken. In questionable cases, intraoperative contrast of ureterography may be performed to exclude ureteral extravasation. If after a thorough evaluation there is still some doubt, the placement of peri-ureteral drains will usually prevent postoperative urinomas and prevent a further delayed diagnosis in the event of an occult injury.

Postresuscitation Pitfalls: The Intensive Care Unit

For every patient, based on the type and severity of injury, age, underlying chronic disease, and response to therapy, there is an anticipated clinical "trajectory." The critical care management of the trauma patients involves several related elements: the monitoring of this trajectory, adjustments in management to maintain this trajectory, the anticipation and prevention of recognized complications (prophylaxis), and the timely management of major deviations from clinical expectations (complications). Pitfalls exist in all of the areas with resultant errors associated with undermonitoring, flawed decision making, failures to establish adequate prophylaxis, and delays in diagnosis related to the original injury or subsequent complications.

Over- and Under-Resuscitation

Given the extreme volume shifts accompanying the resuscitation of patients with major injuries, including massive transfusions, opportunities for too much or too little volume administration abound. The recognized downsides of under-resuscitation include persistent acidosis, possibly persistent coagulopathy, a prolonged shock state, and predisposition to acute respiratory distress syndrome (ARDS) and multiple organ failure, and increased mortality. The recognized downsides of over-resuscitation include extensive tissue edema and parenchymal edema involving the abdominal wall, retroperitoneum, and viscera resulting in the inability to primarily close the abdomen or, in nonoperative cases, even the delayed development of secondary abdominal compartment syndrome. In some circumstances, massive volume resuscitation may exacerbate the development of extremity compartment syndromes as well and potentially exacerbate intracranial pressure (ICP) in the setting of traumatic brain injury.[69,70] Increases in chest wall edema, pulmonary edema, and airway edema may lead to delayed ventilatory weaning and prolonged ICU stays. Even a minor degree of over-resuscitation in the patient with severe pulmonary contusion may exacerbate lung edema and precipitate ARDS.

Presumably, there exists an "optimal" level of resuscitation for each trauma patient, varying over time, but the role of optimizing resuscitation following a major trauma is more difficult to achieve than one might expect and has been the source of multiple investigations over the years. The concept of goal-directed therapy and improving cardiac index and oxygen delivery was formulated by Shoemaker and colleagues[71] and directed at preventing the mortality often associated with inadequate hemodynamic indices. Several meta-analyses have tried to sort out and identify the confusing array of data and have suggested that goal-directed therapy may be of benefit in certain selected patient populations such as preoperative, high-risk elective surgery, but probably has no benefit in other patient populations such as those with sepsis.[72,73] In the trauma population, goal-directed therapy has been popularized by several authors,[74] but data suggesting a clear survival benefit with this approach have yet to be developed. One recent prospective study reported by Velmahos and colleagues[75] failed to find significant overall improvements in mortality, organ failure, complications, or ICU length of stay using a goal-directed approach to resuscitation, and concluded that cardiac index, oxygen delivery, and consumption responses were more markers of physiologic reserve than valid resuscitation targets.

It is important to note, however, that although driving physiologic parameters to specific supernormal goals has not been shown to have demonstrated efficacy in the trauma population, sufficient monitoring to detect deficient physiological responses, particularly related to inadequate preload or inadequate cardiac reserve, is probably important. The degree of over- and under-resuscitation can be mitigated by the use of appropriate preload monitoring including central venous catheter lines, trans-esophageal echocardiography, and pulmonary artery (PA) catheters. Latent failures in this setting, however, include the lack of training and familiarity with advanced monitoring techniques, and inappropriate decision making associated with their use.

The age-old controversy regarding a "fluid liberal" versus "fluid restrictive" approach to critically ill patients was the focus of a recent multi-institutional study. In a prospective randomized comparison of 1000 patients, the ARDS Clinical Trials Network found no survival benefit to either approach, but the data suggested that a more conservative strategy of fluid management is associated with improved lung function and a shorter duration of mechanical ventilation.[76]

Postresuscitation and Postoperative Missed Injuries

Prevention of late missed injury depends on a knowledge of injury patterns, a thorough primary evaluation, and a systematic follow-up examination and review of previous studies. The reported incidence of missed injuries (or delayed diagnoses) varies considerably, from a low of 2% to 3% to more than 60%.[77-79] The vast majority of these are low impact "misses" that have limited clinical sequelae, many of which are more accurately termed "delayed presentations." These include minor fractures (eg, patella, metatarsal, "chip" fractures of the pelvis, and so forth) that are diagnosed later in a patient's hospital course. Neurological

TABLE 16. Potential Missed Injuries (Selected) and Approaches to Error Reduction

Missed injury type	Presentation or common factors associated with delay/miss	Error reduction strategies
Traumatic brain injury	False attribution (drugs, alcohol, seizures) Errors in CT interpretation	Routine CT scans based on threshold GCS/neurological examination.
Axial spine injuries	Reliance on physical examination, false attribution of subtle signs and symptoms	Protocol-driven radiographic series for obtunded patients, CT for primary cervical spine evaluation in higher risk patients.
Carotid, vertebral dissections	Unexplained decreases in LOC	Protocols for duplex scans/MRI in selected cervical spine injuries.
Blunt aortic injury	Initial false negative CXR	Guidelines for chest CT based on age, mechanism, etc.
Blunt intestinal injury	Initial false negative CT, false negative prediction based on CT, Errors in CT interpretation missing subtle signs.	DPL or repeat CT scan for suspicious or equivocal studies. DPL or repeat CT scan for associated seat belt signs or Chance fractures.
Blunt cardiac injury	Non-specific signs/symptoms, failure to obtain EKG	Protocol-driven EKG assessment. TEE/TTE for hemodynamic manifestations.
Pancreatic injury	Initial false negative CT, errors in CT interpretation, false negative DPL	Mandatory follow-up CT for equivocal studies.
Pelvic fractures	Obtunded patient, false negative prediction based on physical examination	Protocol-driven radiographic series for obtunded patients.
Tibial plateau fracture	Obtunded patient, false negative prediction based on examination	Protocol-driven radiographic series for obtunded patients.
Extremity vascular injury	False negative prediction based on pulse examination	ABI screening for all proximity injuries.

From: Dicker RA, Mackersie RC. Pitfalls in the management of the trauma patient. Wilson W, Hoyt D, editors. In: Trauma: Resuscitation, Anesthesia, and Emergency Surgery. 1st ed. Informa Healthcare; 2007.
GCS, Glascow coma scale; CT, computed tomography; LOC, level of consciousness; CXR, chest radiograph; EKG, electrocardiogram; DPL, diagnostic peritoneal lavage; TEE, transesophageal echocardiogram; MRI, magnetic resonance imaging; TTE, transthoracic echocardiogram; ABI, ankle-brachial index.

injury, conscious sedation, and distracting injuries all play a role in diminishing the accuracy of the physical examination as a primary means of detection and increasing reliance on plain and CT radiography has provided 1 means of counteracting these effects.

There is general recognition that the primary and secondary surveys for traumatic injuries, despite being carefully conducted, will result in missed injuries, for all the reasons mentioned previously as well as the demands of prioritizing management of the most serious associated injuries. In teaching programs radiological misreads are an anticipated by-product of less experienced physicians providing preliminary radiological interpretations, and there continue to be diagnostic pitfalls with respect to certain types of injuries (Table 16).

Measures to reduce the incidence of missed injury in a system of trauma care must balance the time/cost/effort required to achieve a near-100% capture rate for significant diagnoses, and the impact of complications resulting from diagnostic delays. A protocol-driven process involving a follow-up, complete and detailed head-to-toe physical examination, and systematic review of all diagnostic studies (tertiary survey) has been shown to significantly reduce the incident of missed injuries.[80,81] In many centers, advanced practice nursing staff perform these follow-up surveys. The process appears to be cost-effective and demonstrates the viability of a "systems" approach to error reduction in a heavily provider-dependent arena. Similarly, the use of guidelines, protocols, or algorithms may direct providers away from suboptimal diagnostic approaches, avoid well-recognized pitfalls, and further reduce missed injuries.

Technical improvement in speed and resolution of diagnostic imaging and increased utilization has acted to decrease the overall incidence of some types of missed injuries. Unfortunately the overuse of imaging, particularly CT, may create problems with false positive studies. Splenic clefts mistaken for major splenic injury, standing wave artifact masquerading as blunt aortic injury, or volume averaging artifacts creating the impression of a ruptured diaphragm are examples.[82-84] The obvious pitfall is predicating decisions entirely on a radiographic image.

Despite improved imaging and increased sensitivity of missed injuries, a few troublesome areas persist.

Missed blunt intestinal injuries. Despite improvements associated the multi-channel CT imaging, missed blunt intestinal injuries (BII) continue to occur. Hollow viscous missed injury rate at initial CT has been reported to be approximately 10%, with mortality related to missed injury reported to be as high as 40%.[85] The radiographic hallmarks of BII may be very subtle and include (unexplained) free intraperitoneal fluid, bowel wall thickening, mesenteric stranding, or frank intraluminal contrast extravasation. Associated clinical findings include seatbelt contusions, Chance fractures, and abdominal pain. The major pitfall resulting in missed injury and preventable morbidity and mortality is the tendency to disregard even subtle CT findings in a higher-risk clinical setting. Most errors of this nature may be avoided by undertaking further diagnostic investigations in any patient at risk. This must include careful serial abdominal examinations, and may additionally involve repeat CT scanning, DPL, laparoscopy, or even laparotomy.

Missed blunt pancreatic injuries. The pancreas is susceptible to blunt fracture, typically near its point of contact with the anterior spinal column, caused by anterior abdominal impact. CT findings may be very subtle, or even nonexistent initially, consisting of nothing more than local edema or some irregularities in pancreatic perfusion. In most cases, short delays in the diagnosis of isolated blunt pancreatic injuries, unlike BII, will have limited consequences, allowing repeat CT imaging or even ERCP in highly suspicious cases. The threshold for repeat imaging should be low and most injuries involving the main pancreatic duct should be evident before proceeding to the operating room.

Missed cervical spine injuries. The missed cervical spine injury with resultant severe neurologic damage has historically been 1 of the most treacherous pitfalls in terms of both impact to the patient and cost, medically and legally. Horror stories regarding occult injuries are well documented in the literature, but most occur in settings in which the errors made were associated with inadequate diagnostic imaging and were potentially avoidable. In some centers, the high-impact potential for misses in these areas has resulted in almost defensive overdiagnosis, with increasing reliance on both CT and magnetic resonance imaging (MRI). Although appropriate for any circumstances, the widespread application of these imaging techniques to the majority of at-risk patients raises questions about proper resource use.

The most common pitfall in this area is the over-reliance on the physical examination for purposes of cervical spine "clearance" in a lower risk setting. Most centers now have protocols in place for clearance of the cervical spine in the awake patient. These protocols help present the practice of clinical clearance in the setting of interfering effects such as drugs or alcohol, distracting injuries, neurologic findings on clinical examination, or other concomitant axial spine injuries. Stiell and colleagues demonstrated that a rule-based approach to cervical spine injury diagnosis can be implemented effectively and result in a minimum number of diagnostic errors.[86]

Missed blunt cerebrovascular injuries. Carotid and vertebral artery dissections can result in devastating neurologic sequela, and occur with probably greater regularity than was originally suspected. Faster CT imaging using 16-channel scans (and higher) has made screening arteriograms more accessible. Recent reports suggest that a protocolized approach for screening for blunt cerebrovascular injuries may be warranted, and institution-specific practice management guidelines for this type of screening are helpful adjuncts for avoiding missed injuries.[87] Despite improvements in early diagnosis, not all reports have shown concomitant improvements in patient outcomes.[88]

Missed blunt aortic injuries. Historically, clinicians have relied on the plain, upright AP chest radiograph as a screening modality for the detection of blunt aortic injuries (BAI). Increasingly, it has been recognized that occult injuries may occur without the typical findings on plain radiographs, particularly in the elderly patient population, and the liberalized use of head-neck-chest-abdomen-pelvis CT imaging with faster scanners has largely resolved the problems of missed BAI. The classic chest radiograph indications of blunt aortic injury include mediastinal widening, depression of the left main-stem bronchus, obliteration of the aortopulmonary window, apical capping, vexation of a placed nasogastric tube, but may also include the findings of other chest injuries including pleural effusion, rib fractures, scapular fractures, clavicular fractures, external fractures, and so forth. Elderly patients with "egg shell" aortas may sustain potentially lethal injury in the absence of any findings whatsoever. The presence of any evidence of chest/torso trauma, chest pain, or simply the mechanism of injury may often provide an adequate indication for dynamic CT Imaging of the aorta in this patient group.

Abdominal Compartment Syndrome and the "Open Abdomen"

A major complication related to massive torso trauma and high volume resuscitation is intra-abdominal compartment syndrome (IACS). IACS in trauma results from massive hemorrhage, which leads to hypoperfusion (particularly to the splanchnic circulation) and ischemia. Subsequently, with high volume resuscitation, tissue edema and reperfusion injury can lead to abdominal compartment pressures in excess of 25 to 30 mm Hg. At this pressure, compression of the renal veins, the inferior vena cava, and the superior mesenteric artery may occur. At this later stage of IACS, the patient is at great risk for development of multiple organ failure and death.[89]

With the advent of damage control laparotomy, a prophylactic approach to ACS has become the standard of care for patients with massive torso trauma. The abdominal fascia is left open at the first damage control procedure, thereby avoiding the potential development of IACS. Temporary abdominal coverage includes skin-only closure (used infrequently), plastic abdominoplasty, temporary mesh, and vacuum-assisted wound closure devices.[90]

The most dreaded pitfall in the prolonged management of an open abdomen is the perforation of the bowel, or bowel anastomotic breakdown that results in a so-called entero-atmospheric fistula, with bowel epithelium exposed in the middle of an open abdomen. This type of fistula is essentially a stoma, lacking the usually fistulous tract, and will never close spontaneously. Exposure of the neighboring bowel loops and abdominal contents to succus from this fistula can lead to local infection and smoldering peritonitis.

Prevention of bowel anastomotic breakdown centers around protecting the bowel while the abdomen is open, and facilitating delayed primary abdominal wall closure. A variety of approaches and materials have been used, most involving the application of a wound vacuum device.[91,92] The most critical steps involve the use of a plastic drape that is placed over the bowel and along the lateral gutters of an open abdomen. Failure to place a barrier separating the intestinal block from the abdominal wall may predispose to fistula formation as well as impede abdominal wall closure eventually.

Delayed primary closure at the earliest opportunity should be the goal of wound management. This may be achieved by the use of elastic tensioning devices, sutures, or even the temporary placement of high tensile strength mesh for graduated closures. This approach takes vigilance, with frequent trips back to the operating room. In some cases, delayed primary closure may be facilitated by the use of component separation for definitive abdominal wall closures.

When delayed primary abdominal closure cannot be achieved, the use of other materials, such as absorbable mesh or acellular dermal matrix may provide sufficient protection of the bowel and allow eventual skin grafting to affect more durable closure. The large abdominal wall hernia, which seems inevitable even with newer materials, can subsequently be addressed several months down the line, when the patient has recovered and the local wound inflammation has subsided.

Prolonged Weaning from Mechanical Ventilation

One of the primary and unique functions of a critical care team, and 1 that often occupies considerable time and effort, is the management of weaning from mechanical ventilation. Ventilator weaning is the transition process by which the patient, as opposed to the mechanical ventilator, assumes the function of the ventilatory pump—moving air in and out of the lungs. Optimized weaning, with reductions in ventilator days, may be associated with decreased infections, particularly ventilator-associated pneumonia (VAP), improved outcomes, and reduced costs. A couple of important pitfalls exist that may lead to delayed ventilator weaning.

Oversedation. Oversedation in the ICU is a widespread practice. Liberal use of narcotic and benzodiazepine infusion has become the rule in many ICUs, with the laudable goal of minimizing pain and anxiety. Metabolism of these medications may be slowed significantly under certain circumstances common in this population. In addition, preexisting derangements in hepatic metabolism, particularly common in the elderly, can also prolong the effect of sedative medications. Oversedation or prolonged sedation can markedly prolong the ICU stay by delaying the time to extubation and exposing the patient to opportunistic infections, most notably VAPs.

In additional to the use of sedation-guidelines in the ICU, recent studies of the relationship between sedation and ventilator weaning have suggested that planned interruption of IV sedation may shorten ICU stays. Kress and colleagues, in a randomized study, demonstrated decreased duration of mechanical ventilation and decreased ICU length of stay when patients underwent planned daily interruptions in sedation. This daily interruption and awakenings allowed for better titration of sedation, and appear to avoid some of the problems of oversedation associated with a lesser degree of assessment.[93,94]

Lack of specific weaning protocols. Previous investigation examining regimens for ventilator weaning suggest that more rapid progress could be made if a process of intermittent breathing exercises were utilized.[95] These observations led to specific protocols directing the weaning process, but physician-implementation of these proved to be suboptimal in many environments. The subsequent large-scale implementation of respiratory therapist-driven ventilator weaning protocols began several years ago, largely in medical ICUs.[96] Since the original publications suggesting decreased ventilator days, other investigators have duplicated the outcomes.[97] More recently, protocol-driven weaning has been taken to the next level: computer-driven weaning protocols. In this model, a closed-loop knowledge-based algorithm introduced in a ventilator implemented an automatic gradual reduction in pressure support and automatic spontaneous breathing trials. Results indicated that this model reduces time to extubation, reduced critical care lengths of stay, and did not lead to higher reintubation rates.[98]

The experience of protocol-driven ventilator weaning in surgical patients has not been as extensive as in medical ICUs, although efforts are under way to test the implementation of these protocols in the broader population. A recent review of protocol-driven weaning, when applied to injured and other surgical patients, reflected similar results to that of medical patients; protocol implementation led to more ventilator-free days and lower rates of ventilator associated pneumonia.

Pitfalls in the Recovery Phase

Lost Opportunities for Functional Recovery

The ultimate test of a trauma system is its ability to restore the trauma victim to a level of function equivalent to the preinjury level. Unfortunately, the focus of most systems remains on acute care and critical aspects of functional recovery are often overlooked. The requirements for optimal functional recovery are considerable and include aspects of psychological, physical, and financial wellness. In addition, assessment of the potential for reinjury and development of strategies to prevent this injury recidivism ideally round out a scheme to ensure complete treatment of the trauma patient.

A report published from the Trauma Recovery Project in San Diego revealed substantial functional limitations at 12- and 18-month follow-up of trauma patients.[99] Using a standardized quality-of-life scale, depression, post-traumatic stress disorder (PTSD), serious extremity injury, and number of intensive care unit days were associated with functional limitations.[99] Additional data from this investigative group have identified women as being at higher risk than men for worse quality of life and early psychological morbidity such as PTSD following major trauma.[100]

The psychological impact of trauma can be tremendous, and the pitfall consists of a tendency to overlook or disregard the psychological impact of major injury. Diagnostic aids, in the form of simple questionnaires, can assist primary providers in recognizing depression and PTSD, and is an important first step in linking the patient to institutional consultation and long-term treatment for these disorders. Treatment is essential to avoid the potential consequences such as sleep disturbance and poor motivation that can greatly hinder physical recovery.[36]

Neurologic injury in particular is associated with compromised outcomes, and the impact of traumatic brain or spinal cord injury may be further exacerbated by delays in integrating early occupational and physical therapy services for early mobilization, and inadequate discharge planning and placement. Discharge planning is often a complex multidisciplinary activity ideally involving inpatient providers, rehabilitation medicine specialists, social workers, primary care physicians, and mental health professionals. Transitions to home or rehabilitation facilities are often stressful, further complicated by erroneous or misguided family expectations or insurance issues.

The financial burden of a traumatic event can be extremely disconcerting to patients, and a high percentage of recovering patients regard vocational and financial issues as areas of primary concern.

Failures in Postinjury Risk Reduction: The Problem of Recidivism

For many patients, traumatic injury is not the result of a once-in-a-lifetime catastrophe, but a common by-product of lifestyles and environment that carries high risks. If traumatic injury is to be considered a "disease" that is potentially preventable, then the treatment of index events (injury) should also incorporate measures to reduce injury recidivism in high-risk populations. Very much like postmyocardial infarction treatment incorporates lifestyle changes as part of the disease management process, so should the postinjury treatment of certain populations of trauma patients.

Individuals injured from interpersonal violence, for example, often share characteristics such as poor education, unemployment, dysfunctional homes, and poor life skills that may be associated with recurrent injury. The reported injury recidivism rates for this population approaches 35%. Postinjury management that incorporates institutional and community resources designed to alter some of these environmental factors may help reduce recidivism rates.

Falls occurring in the elderly population, another example, are often associated with identifiable risk factors including overmedication (polypharmacy), lack of home safety devices, neurologic disorders, and poor mobility. Fall recidivism in some population is as high as 50%, and the disease management process for this type of injury should ideally consider measures directed at these risk factors.

Preliminary data now support the notion that the mentally ill are also at higher risk for unintentional injury and injury recidivism.[101] Opportunities for postinjury recidivism risk reduction may involve specific psychiatric intervention as well.

Although not commonly regarded as a pitfall for acute care providers, lost opportunities to intervene as part of the overall disease management process for trauma may, in fact, be an important cause of recurrent preventable injury. Hospitals and providers do not typically view themselves as responsible for these aspects of trauma care; however, but there are likely outcome advantages of attending to these matters in the acute setting.[102]

Global Pitfall: Access to Trauma Care

This monograph is directed toward individual practitioners who are involved in the care of individual trauma patients and presumably trying to avoid common pitfalls in their management. Other studies have helped provide a more global overview of errors following major trauma.[103] The value of system-based practice is increasingly recognized in both training programs and postgraduate education, and a discussion of pitfalls would be incomplete without mention of problems, errors, and pitfalls that exist on a more global scale, involving the entire health care environment.

The recent Institute of Medicine report noted overcrowding, uncompensated care, specialist unavailability, hospital diversion, and other factors as being important in limiting access to emergency care, and many believe that emergency care represents the proverbial "canary in the coal mine" for the rest of the American health-care system. Studies have suggested that more than one third of major trauma patients do not access appropriate designated trauma facilities (Level 1 or Level 2 trauma centers) in the course of their treatment.[104,105] Strangely, this is against the background of the demonstrated effectiveness of trauma systems and trauma centers in improving outcomes from trauma care.[106,107]

Although geographic isolation may affect a small portion of the population, the principal defect in access to trauma care is the lack of participation by institutions and by specialist providers. Participation in trauma systems are determined principally by 2 factors: (1) the economic viability of such participation; and (2) physician participation, particularly the subspecialties. Factors impeding institutional participation include the increasing threats of decreased contractual commitments, adverse payor mix, opportunity costs, and lack of physician commitment. Factors impeding physician participation include increased medical liability, the lifestyle disadvantages of a trauma practice (eg, long work hours, overnight call, and so forth), and similar opportunity costs in areas in which general surgeons also have elective practices.

The overall effect of decreased provider and institutional commitment to trauma care has been to inundate a relatively small number of designated centers with all of the trauma in a given region, including more minor injuries, creating an "exclusive" system of care and possibly compromising patient outcomes.[108] The development of specialty hospitals, acting to draw both patients and talented physicians away from the general pool of health-care resources, also acts to further restrict access to care.

Several factors are currently in play that may help limit the contraction of our trauma systems. These include the reinstatement of Title 12 by Congress in mid-2007, an ongoing interest in trauma systems development on the part of the individual 50 states, and the now widely recognized need for improved disaster preparedness. Creative models for providing increased physician and institutional incentives (eg, tobacco taxes, alcohol taxes, property tax supplements, pay or play fees for nonparticipating hospitals, driving under the influence [DUI] and vehicular surcharges, and so forth) may help improve provider and institutional commitment to trauma care.

Other larger environmental factors affecting the delivery of trauma care include substantially altered surgical training programs with major reductions in house staff hours, the increasing use of advance practice staff (eg, nurse practitioners, physician assistants) to augment and help protocolize care, and the recent initiation of the federal "pay for performance" program. The entire field of medicine is in a particularly dynamic state with regard to personnel and systems. The care of the trauma patient will certainly continue to be impacted by these changes. Anticipating potential problems will arm us to minimize pitfalls in a rapidly changing environment.

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