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SYSTEM FOR INITIAL ASSESSMENT, MANAGEMENT, AND PHYSIOLOGIC MONITORING OF BATTLEFIELD CASUALTIES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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In combat, the evaluation, management, and monitoring of the critically injured may involve handling mass casualties in a confused and hostile environment. If so, it will be advantageous to have a combat casualty management system which provides maximum decision-making assistance to medical personnel in minimum time.

Key features of the proposed system include: (1) modularity, (2) sequencing of data acquisition, (3) quantitative scoring systems, (4) computers to store and manage data and guide decision making and therapy, (5) use of commercially available hardware, (6) optimal layout of the second echelon facility, (7) establishment of clinical test sites, and (8) peacetime practice use. Data will be collected by using: (1) observation and a hand-held computer, (2) portable, noninvasive monitors, and (3) nonportable/invasive monitors.

Of the scoring systems proposed or in use, the trauma score and injury severity score appear to be most accurate. National efforts now exist to improve their accuracy by assessment of

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data from major university trauma centers. Modifications to account for the effects of chemical, biological, and radiological warfare will be needed.

Key components of the software development are: (1) identification of critical data, (2) design of user friendly systems, (3) multiple data entry capability, (4) development of data evaluation processes and decision-making algorithms, (5) generation of alert messages, and (6) capability to act as a teaching aid.

To date, the "HELP" system used at the LDS Hospital in Salt Lake City most closely approaches these goals.

SUMMARY

In the initial evaluation, management, and monitoring of the critically ill or injured, there is frequently a need to gain control and provide immediate support while, or even before, proceeding with multisystems assessment and measurement of key physiologic variables. In combat, these concurrent activities may need to be accomplished under adverse circumstances in which relatively large numbers of casualties, with potential injuries of chemical, biological, or radiological (CBR) as well as mechanical causes, must be received and treated by health care personnel whose numbers, medical training, and resources are relatively limited, in a confused, and hostile environment in which the nature of injuries may pose lingering threats to casualties and health care workers alike. For this environment of high stress, workload, confusion, and risk, it will be advantageous to design a combat casualty management system which provides maximum decision-making assistance to health care workers at all echelons.

Key features of the proposed system include the following: (1) modularity, so that advances in state-of-the-art of individual components easily can be incorporated into the whole; (2) careful sequencing of data acquisition, so that maximum information is obtained by simple straightforward means before use of more complicated device/technician dependent studies; (3) use of quantitative scoring systems with which to grade severity and predict outcome of critical illness and injury; (4) use of computers for acquisition and management of data, and guidance of decision making and therapy; (5) use of carefully selected commercially available computer hardware, with internal R&D efforts focused on software appropriate to the battlefield setting; (6) structural design of the second echelon (2E) facility to enhance accomplishment of the mission it is expected to perform; (7) establishment of clinical "test sites" at which to validate concepts and devices; and (8) peacetime operation of fully integrated computer data management and medical decision-making systems, in military and university patient care environments, to serve as educational as well as R&D centers.

Data to be sought and variables to be monitored in a 2E facility may be classified, according to ascending order of complexity, as follows: (1) data which can be acquired by an observer without monitoring devices, with exception of a hand-held "scratch pad" computer with liquid crystal display and integral memory, and possibly a blood pressure cuff; (2) data which can be acquired with simple, hand-held or portable, noninvasive monitoring devices, with minimal "technician dependence"; and (3) data whose acquisition requires more complex, less portable devices or/and invasive techniques. Specific recommendations in each category

are provided, as are suggestions as to how field-rated equipment might be adapted from devices which are commercially available, being developed for the National Aeronautics and Space Administration's (NASA) space station, or being prototyped in university settings.

Of scoring systems proposed and in use, the trauma score and injury severity score currently appear the most promising as regards accuracy of outcome prediction. Efforts are now underway nationally to improve the accuracy of these scoring systems through assessment of pooled current data contributed by a number of major university trauma centers. Modifications are needed to account for the effects of CBR warfare agents.

The 2E computer system hardware should be compatible with both the projected data manipulation tasks and battlefield environment. It should include hand-held, "scratch pad" computers with which to accomplish initial screening data entry, including information directly from dog tags, and a central computer system, managing information for the entire 2E facility via integrated medical information buses and a common data base. Key components of software development are the following: (1) selection of appropriate variables to input and amounts of memory to devote to storage relative to demonstrated amounts of data recall and use; (2) design of user friendly screen presentations which facilitate rapid manual entry of data; (3) emphasis on automatic entry from as many points of data origin as possible so as to maximize information available for decision making; (4) construction of data evaluation processes and decision-making algorithms which parallel those of the best physicians and which are automatically initiated or driven by arrival of new data; (5) generation of "alert" messages, which draw attention to undesirable patient conditions, provide possible differential diagnoses, and offer suggestions for confirmation and correction; and (6) creation of a system which also functions as a teaching aid for medical personnel. To date, the "HELP system," in use at the LDS Hospital in Salt Lake City, most closely approaches these goals.

Insofar as possible, the 2E facility should be configured structurally to facilitate accomplishment of the mission it is expected to perform. The physical plant should be designed to allow for triage, decontamination, assignments to appropriate levels of care, corrections of errors in triage and care assignments, and patient dispositions - all within the context of the decision-making logic system. To achieve design compatibility, input should be sought from medical and bioengineering specialists with experience in trauma and critical care.

Clinical test sites will be needed at which to evaluate efficacy of new monitoring devices, scoring systems, and data management and decision-making logic. Productive sites for these activities would be busy intensive care units in busy civilian trauma centers. One way for the military to access this environment would be to establish ongoing relationships with selected university departments of surgery, bioengineering, and medical computing. Further, the entire system should be operational continuously in a patient care environment. Therefore there should be developed, in a military and/or a major civilian trauma/critical care teaching hospital, a fully integrated computer data management and medical decision-making system, based on an expansion of HELP system described in this report.

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INTRODUCTION

In the evaluation and management of critical illness and injury, whether in a major civilian medical center or forward (second echelon (2E)) battlefield medical care facility, the following questions are both key and common: (1) What information is required? (2) When is it needed? (3) How should it be obtained, organized, interpreted, and acted upon? (4) How may the effect of intervention be accurately evaluated? (5) How may immediate support, when necessary, be provided while acquiring the data base?

Even for non-life-threatening situations in civilian practice, answers to these questions may not be so "common" for several reasons: (1) There frequently is influence of biologic variability: Two patients with similar underlying problems may manifest different initial symptoms and findings; conversely, patients with different underlying illnesses or injuries may present with similar patterns of initial symptoms and findings. (2) There frequently is presence of multisystems involvement, wherein relatively limited initial symptoms and findings may reflect the aggregate manifestation of damage to or dysfunction of several organ systems, all of which require evaluation and management. As the complexity of disease process increases and the "conditions of practice" become more adverse, satisfactory answers become both more important and more difficult to derive.

With critically ill and injured patients, time is a significant factor influencing the approach in either civilian practice or a combat environment. There is dichotomous pressure, on the one hand for swiftness and on the other hand for certainty and thoroughness. A given patient may tolerate neither delay nor error. Initial evaluation, management, and monitoring are not independent. There is a need to gain control and provide immediate support while, or even before, proceeding with multisystems evaluation and key physiologic parameter monitoring. This implies the need to establish algorithms and priorities by which components of evaluation, management, and monitoring can be appropriately and rapidly sequenced. It is important to diagnose and initiate treatment of potentially life-threatening and permanently disabling conditions before time and attention are devoted to lesser, even though perhaps more readily recognized, problems.

In these regards, the combat environment poses particularly challenging and adverse conditions. In addition to dealing with multisystems damage and failure as well as single organ

involvement, and critical illness and injury as well as non-life-threatening problems, it may be necessary to contend with all of the following: (1) multiple causes of injury: chemical (gas), biological (microbial), radiological (nuclear), and mechanical, instead of single mechanisms; (2) battlefield confusion instead of hospital organization; (3) potential simultaneous arrival of relatively large numbers of casualties rather than presentation of 1 or 2 patients at a time; (4) relatively limited numbers of medical care personnel with relatively general or/and limited training rather than a relative abundance of a spectrum of specialists; and (5) environments (chemical, biological, and radiological warfare) which may pose a lingering danger to casualties and health care workers alike, thus inhibiting immediate access to patients for evaluation, treatment, and monitoring. To maximize effectiveness, a system for initial evaluation, management, and subsequent physiologic monitoring of battlefield casualties must account for all these conditions and constraints. It is the intent of this report to suggest a framework within which to do so, while also addressing the more specific original question of which parameters to monitor and how to monitor them.

INITIAL ASSESSMENT MODALITIES

With regard to initial evaluation of combat casualties, it is instructive to consider what is currently done to evaluate patients presenting to major medical centers, and why. It is convenient to consider at least two categories of patients: (1) those who can provide a history, can cooperate with physical examination, and whose life or limbs do not appear to be in imminent jeopardy; and (2) those who cannot provide a history, cannot cooperate with physical examination, or who appear to be in immediate danger of loss of life or limb.

For the first category, initial evaluation usually consists of eliciting chief complaints and obtaining a focused history, followed by a directed physical examination. Laboratory, radiographic, and other special studies and physiologic monitoring are usually relatively selectively employed to confirm or disaffirm problems suggested by the former components. Initiation of therapy, in turn, usually follows confirmation of diagnoses to a reasonable degree of certainty.

For the critically ill or injured patient category, as previously stated, initial evaluation and management are much less independent. An overall protocol in these circumstances can usually be described by the following series of steps whose sequence is determined by priority of the action required to address the related problems, if present: (1) control of brisk external hemorrhage; (2) control of airway and ventilatory support; (3) establishing vascular access; (4) obtaining blood

samples (concurrently with vascular access) for ex vivo determination a limited number of selected, key variables (with expectation of some delay in return of data); (5) rapid clinical assessment and initiation of replacement of blood loss; (6) "first pass" physical examination, and initial treatment of specifically sought injuries (with particular emphasis on immediately life-threatening chest injuries and immediately limb threatening skeletal-vascular injuries); (7) sequencing of special studies (diagnostic imaging, diagnostic peritoneal lavage, additional laboratory measurements, etc.) with "second pass" physical examination; and (8) removal to operating room or intensive care unit for treatment and physiologic monitoring. As the data base accumulates, whether at a glance or in a step-wise fashion, this sequence may need to be modified according to specific injuries identified and stability of the patient's course. For example, it may be appropriate to (temporarily) relieve a tight tension pneumothorax or cardiac tamponade prior to inserting an intravenous fluid infusion catheter (1-11).

For both categories of patients, it is noted that special studies and physiologic monitoring enter toward the end of the lists (1-11). The preceding, less "device-dependent," maneuvers have been found to provide the most relevant information per unit time in the safest and most cost-effective fashion as regards immediate decision making, including decisions related to choice of the optimum confirmatory study or the most appropriate monitor. This order of priority does not imply that special studies and device-related monitoring are not crucial in accurately confirming diagnoses and guiding therapy, or that their application need be much delayed in time from onset of initial evaluation. For example, for the patient complaining of severe chest pain suspicious for myocardial origin, electrocardiographic monitoring often is commenced within a few minutes of arrival, preceded only by brief physical examination assessment of adequacy of ventilation and pulse, and establishment (often simultaneously) of intravenous access and administration of supplemental oxygen. What is noteworthy, however, is that even in major medical centers where, presumably, any currently available special study or monitoring device is available, these modalities are not preferentially applied in the <u>initial</u> evaluation, for the reasons described.

Demonstrated preference in clinical practice has significant implications with regard to desire to optimize protocols for initial evaluation, management, and monitoring in the combat environment. At each site and phase of the front-line, second-echelon (2E) facility evaluation and management process, and with particular attention to the earliest encounters with casualties, it will be important that the plan be designed so as to offer opportunity to maximize information obtainable immediately by straightforward, limited questioning and physical examination. This conclusion does not imply that devices will not be useful in guiding acquisition of initial history, performing initial physical examination, and recording the

data. In fact, given the possible adversity of conditions previously described (large numbers of casualties being received by relatively limited numbers of medical personnel with relatively limited training, in a relatively confused and hostile environment), it is recommended that hand-held computers be employed at the earliest point of contact in the 2E facility to prompt for and record the relevant information.

With regard to these earliest evaluations, it is expected that these hand-held computers will represent teaching as well as data management tools. While the devices will remain the primary means of data entry and recording, it can be anticipated that dependency upon and frequency of use of prompts for key questions and components of examination will decrease as experience level of the user increases. Using these devices in simulated casualty exercises, therefore, should constitute an excellent training regimen.

INITIAL EVALUATION AND MANAGEMENT PROTOCOLS

A number of relatively comprehensive, current references on management of major trauma are available (1-11). One of these, the American College of Surgeons' (Committee on Trauma) Advanced Trauma Life Support (ATLS) course workbook (11) is of particular note because it constitutes somewhat of a consensus opinion which is updated at annual or biannual intervals, and, therefore, it represents somewhat of a national standard. For this report it will be neither possible nor appropriate to try to reproduce significant segments of these writings. However, the following points are of note:

Prioritizing Both Injuries and Patients

(1) Given the possible adversity of conditions previously described, it will be important to convert to computer prompts as many of the evaluation and management sequences and algorithms as possible.

(2) Given the magnitude of possible combinations of multisystems injuries, each of varying severity, experienced trauma surgeons and medical computing engineers have found it exceedingly difficult to define "closed" decision trees and algorithms which lead beyond "first pass" evaluation and management. (Of course, as previously noted, it is these early steps which are most likely to be satisfactorily memorized after several "cycles.")

(3) One way to circumvent the limitations of "one-way in, one-way out" decision trees is to prioritize the management of injury to each major organ system or/and anatomic region relative to others. Many major texts are only marginally if at all successful in accomplishing this goal because, as edited, multi-

authored works, it is difficult to maintain a consistent theme from one chapter to another. The American College of Surgeons' ATLS material (11), even as a multi-authored effort, has succeeded fairly well in emphasizing relative priorities. One of the writers of the present report, in a previous single authored chapter (10), placed particular emphasis on identifying relative priorities of injuries to different systems and describing how management of one injury influences another. Keeping track of these relative priorities is a task programmable in computer logic.

(4) Although aimed more at the (rural) community hospital rather than the major medical center physician, even the American College of Surgeons' material is scant in attention to the issue of how to stabilize and monitor major injuries in a compromised medical environment. The present author (10) attempted to address some of the considerations attendant to management in a rural community hospital with relatively scant support resources, versus decision to effect early transfer (evacuation) to a larger facility. Programs of both the recent federal emergency medical services systems act (12) and the current American College of Surgeons' Committee on Trauma (13,14) emphasize the importance of categorizing level of care capabilities of medical facilities and establishing criteria for transfer from smaller to larger facilities. Unfortunately, however, political and financial considerations too often have thwarted effective categorization and transfer agreements in civilian practice.

In the military environment, there are likely to be fewer political and financial disincentives to accurately and formally categorizing levels of trauma care available; yet, in the combat environment, it often may be functionally more difficult to effect transfers. Despite the anticipated difficulties with interfacility communications and patient transport on the battlefield, the previously described adversities of conditions of practice in the combat environment make it even more important to define, in advance, criteria for seeking additional care and, to the extent possible, to create computerized algorithms for: (1) matching patient conditions to criteria for local care versus evacuation, and (2) identifying the most appropriate higher echelon facility when evacuation is indicated.

(5) No current and comprehensive resource adequately addresses the disaster planning issues related to managing large numbers of casualties relative to available health care workers, and doing so in an environment of continuing danger to everyone. To most appropriately match limited resources to apparent needs in these circumstances requires triage, wherein decisions must be made concerning priorities of who should be treated, and not treated, often before considering priorities of what specific injuries should be treated, and not treated. Relatively ineffective in their discussions of injury prioritization, civilian references have been even more negligent in their consideration of patient prioritization. When patient "sorting"

is necessary in civilian practice, the dominant principles have been as follows: (1) The experience and judgment of relatively senior physicians and nurses are used (it is assumed such personnel are "always" available), (2) to identify relative severity of illness and injury of patients as "early" and as "far forward" as possible, (3) so as to direct attention first to the most critically ill or injured, (4) with the assumption that, given relatively "unlimited" resources relative to needs, treating the most serious problems first will maximize survival among the entire patient population. For only a few categories of injuries, such as the 95% deep second - and third-degree burn, is there general agreement, before the fact, that it is appropriate to withhold all-out treatment. For those few categories, the agreement not to treat is based upon a well-established track record of almost certain failure, no matter what the effort expended, rather than upon a concern that the expenditure of resources may jeopardize the outcome of other initially less seriously injured patients with better chances of survival given adequate effort. For all categories, written agreements usually have been assiduously avoided, probably out of concern for legal and financial implications. It is rare that any consideration is given to risk factors for health care personnel.

Combat (and Mass Disaster) Triage

In the combat or mass disaster situation, it is clear that several of the principles upon which civilian triage practices often are based are not applicable.

(1) Those personnel available at forward sites of triage may not be capable of both rapidly and accurately assessing relative severity of injury, based on "experience."

(2) Given potentially severe limitations of resources relative to needs, directing intensive care efforts first to the most critical casualties could jeopardize the outcome of other less seriously ill and injured, and thereby fail to maximize survival (and subsequent combat availability) among the entire patient population. Indeed, even in the civilian literature, there is increasing recognition that those patients who require the most effort and consume the most resources are often the least likely to survive, suggesting need for better criteria for intensive care unit admission (15-18).

(3) It is essential that triage and other medical contingency decision-making algorithms account for potential primary and secondary risks to patients and health care workers alike, with particular attention to the less visible and potentially lingering threats associated with CBR warfare. In this regard: While it is true that limiting exposure of the uninjured is sometimes the most certain means of maximizing future numbers of combat-ready personnel, the programmed cautions cannot be so extreme that rational people

frequently disregard them in order to help other humans in need. To avoid obvious disparity between the safety rules and the realities of working conditions, the 2E level facility should be designed, from the outset, to protect health care workers while allowing rapid treatment of casualties. (This concept will be expanded upon later.)

(4) The requirement to attempt to meet extensive medical needs using limited health care resources, the desire to optimize the ability to do so, and absence of the same legal visibility associated with typical civilian medical practice, represent strong incentives to codify triage and other medical contingency decision-making algorithms, in advance, insofar as possible. Computerized processing and presentation is desirable not only for local decision-making assistance to medical personnel under demanding circumstances, but because of ease with which combat commanders may communicate to medical personnel changes in battlefield conditions so that the latter may adjust or update baseline data upon which certain medical care decisions may be based.

To illustrate this last concept, consider the following variables: severity of injury, ratio of available health care workers to injured, and potential risk to health care workers (such as that associated with lingering effects of CBR agents). As baseline assumptions, decisions to treat or not treat casualties might be represented as follows (Fig. 1):

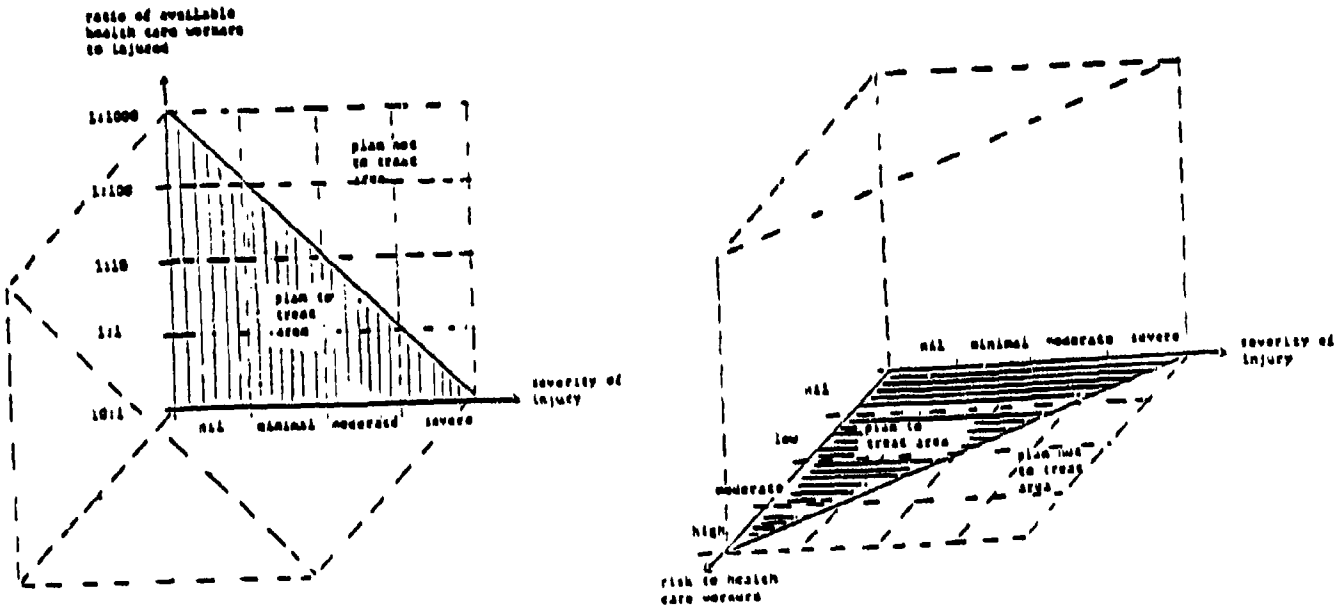

Figure 1. Factors in decisions to treat or not to treat casualties.

When the two-dimensional "plan to treat" areas are projected upon their corresponding third axes in 3-space, and the resulting "solids" are intersected, a "plan to treat" space is defined (Fig 2):

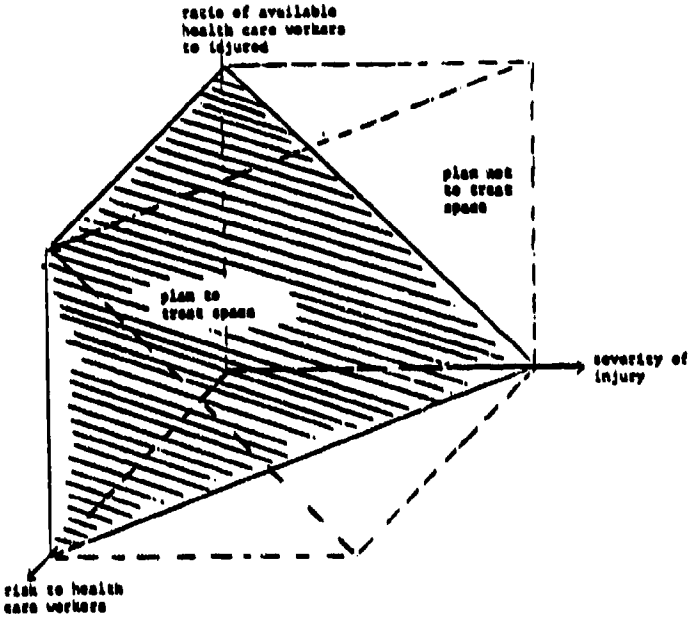

Figure 2. Multidimensional "plan to treat" space.

While visually it is possible to portray only 3 axes, "state space" mathematics conceptually can handle any countable number ("N") of variables, as long as the decision-making relationship of each variable to others can be defined. As changes in current values of some variables become known to a battlefield commander, changes in combat casualty management decisions could be influenced immediately by computer entry of new values or weighting factors for these variables, without having to individually consider the impact of these changes upon a host of other variables and component decisions. For example, a commander with an overview of the battlefield situation could become aware, well in advance of ability of an individual 2E facility to recognize the fact, that a recent increase in numbers and severity of injuries is likely to be a sustained rather than a transient problem. This information, important in influencing allocation (and resupply) of resources at the 2E level, could be rapidly (and, possibly, "directly") entered into the medical decision-making data base, so as to redefine the "plan to treat" space.

Injury Scoring Schemes

An argument obviously is being developed: (1) for use of microcomputer data input, processing, and presentation, (2) by medical personnel with relatively limited experience, (3) for

categorizing, triaging, and otherwise "sorting" patients, (4) with the intent to guide early decisions related to delivery of initial care and use of resources. Clearly this effort will be aided by use of schemes for quantifying assessment of injury and illness. Adaptation of existing numerical scoring schemes, to the extent they are both in regular use in civilian emergency medical services (EMS) systems, and applicable to the combat setting, will be beneficial because their validity continually is being assessed and tested in practice as well as in theory.

A number of scoring schemes have been proposed (15-61) and reviewed (33-43) in association with studies of civilian trauma and delivery of intensive care. Recent modifications generally can be classified as follows: (1) those reflecting an early assessment of physiologic performance, prior to knowledge of specific injuries (19-26); (2) those reflecting an interval assessment of anatomic damage, including symptoms referable and damage to specific organs and body components, compiled at any point in time from all data available from history, physical examination, radiographic studies, and operative findings (27-32); and (3) those reflecting interval assessment of overall severity of disease process, integrating current and past physiologic status with intensity of care requirement and response to care delivered, with particular focus upon effort versus outcome in the intensive care unit (15-18,44-61). In analogy to the different information contained in the preoperative clinical staging of a cancer, as contrasted to the postoperative anatomic/histologic pathology report, or to the immediate postoperative recovery course, these scores provide somewhat different perspectives, usually in sequence.

Relative to applicability in a 2E medical facility environment, there are in each of these categories some scoring systems which almost certainly are excessively complex (30,31,44,51), and some which are potentially applicable (21,25-29). Of those potentially applicable, 2 scoring schemes which so far appear promising in civilian trauma management studies are the physiologically oriented trauma score (25), and the anatomically oriented injury severity score (27-29). The trauma score (TS) incorporates the Glascow coma scale, an assessment of level of consciousness based on straightforward observation of best ability to open eyes, respond verbally, and move limbs, which has proven to be a remarkably accurate index of neurologic status (21). Appendix A describes the trauma score; Appendix B describes the abbreviated injury scale (AIS), from which the injury severity score (ISS) is derived.

As previously suggested, one of the key benefits of adapting regularly used schemes is ability to assess their accuracy in predicting outcome. Of definable outcomes, survival versus nonsurvival is certainly the least arguable. Early results of retrospective application of these scoring

systems, to medical record data of patients delivered to major trauma centers, suggest that there may be such predictive value.

The Trauma Score

For the TS, a review of 1,509 patients with blunt or penetrating injury (34) revealed the following distribution:

Trauma Score	Percentage Survival
16	99
15	98
14	96
13	93
12	87
11	76
10	60
9	42
8	26
7	15
6	8
5	4
4	2
3	1
2	0
1	0

Abbreviated Injury Scale; Injury Severity Score

For the AIS, review of 2,128 motor vehicle accident victims (28) revealed a nonlinear relationship between cumulative numerical score and death rate. This observation suggested need for a means by which to account for variations in mortality associated with number of body areas involved, severity of injury in each, and age of patient. Manipulation and study of the data indicated that mortality rates best correlated with the sum of the squares of the AIS grades for each of the 3 most severely injured anatomic categories. Accuracy was lost if scores of only the 2 most severely injured areas were considered; no appreciable accuracy was gained by considering the fourth most severely injured area. Therefore an ISS was defined as the sum of the squares of the highest AIS grades in each of the 3 most severely injured areas (28). With exclusion of those dead on arrival, and use of dotted lines to indicate less than 10 patients, a plot of mortality versus ISS for 3 age groups showed the following (Fig. 3):

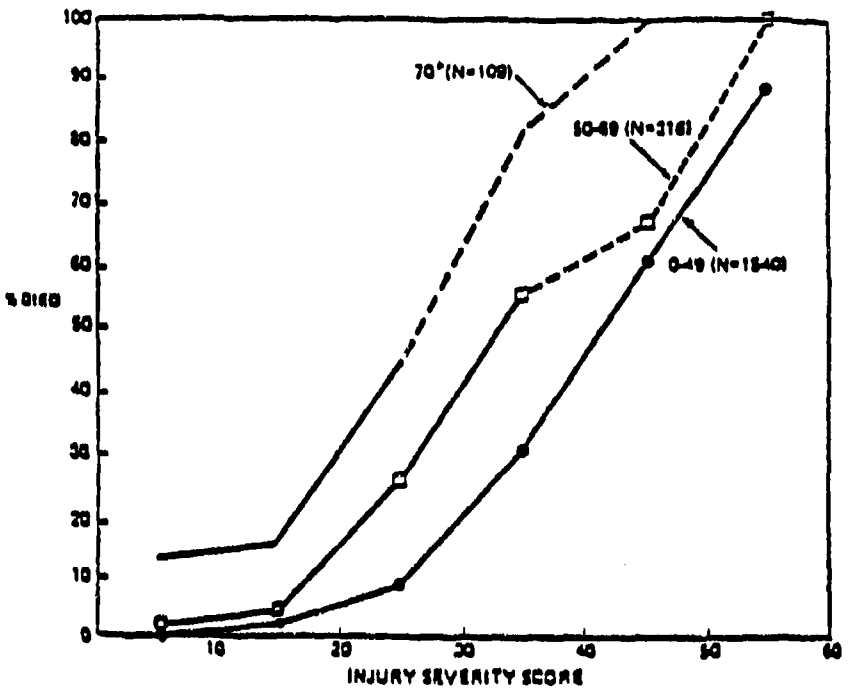

Figure 3. Mortality vs. injury severity score.

Use of Injury Scores

Using either scoring system prospectively, there should be reluctance to predict outcome for patients whose scores are in midrange; however, for scores at either extreme of either scale, the level of confidence can be relatively high. Although probability of survival is not the only issue in classification of casualties, the ability of nonspecialists to predict outcome with relative accuracy clearly has important implications with regard to allocation of limited local medical care resources, appropriateness and consistency in use of evacuation, overall casualty management planning, and audit of effectiveness and efficiency of management.

As regards the issue of audit, the ability to systematically compare performance of each 2E facility to that of other similar units or to some "absolute" standard (e.g., national civilian trauma center data) offers the opportunity to identify factors contributing to either excellent or "sub-standard" performance, and, in turn, to appropriately direct attention and resources to improve performance where possible or necessary. It has been suggested (35) that quality of care delivered in each civilian trauma center might be reflected by plotting the intersection of TS and ISS for their survivors and fatalities (Fig.4).

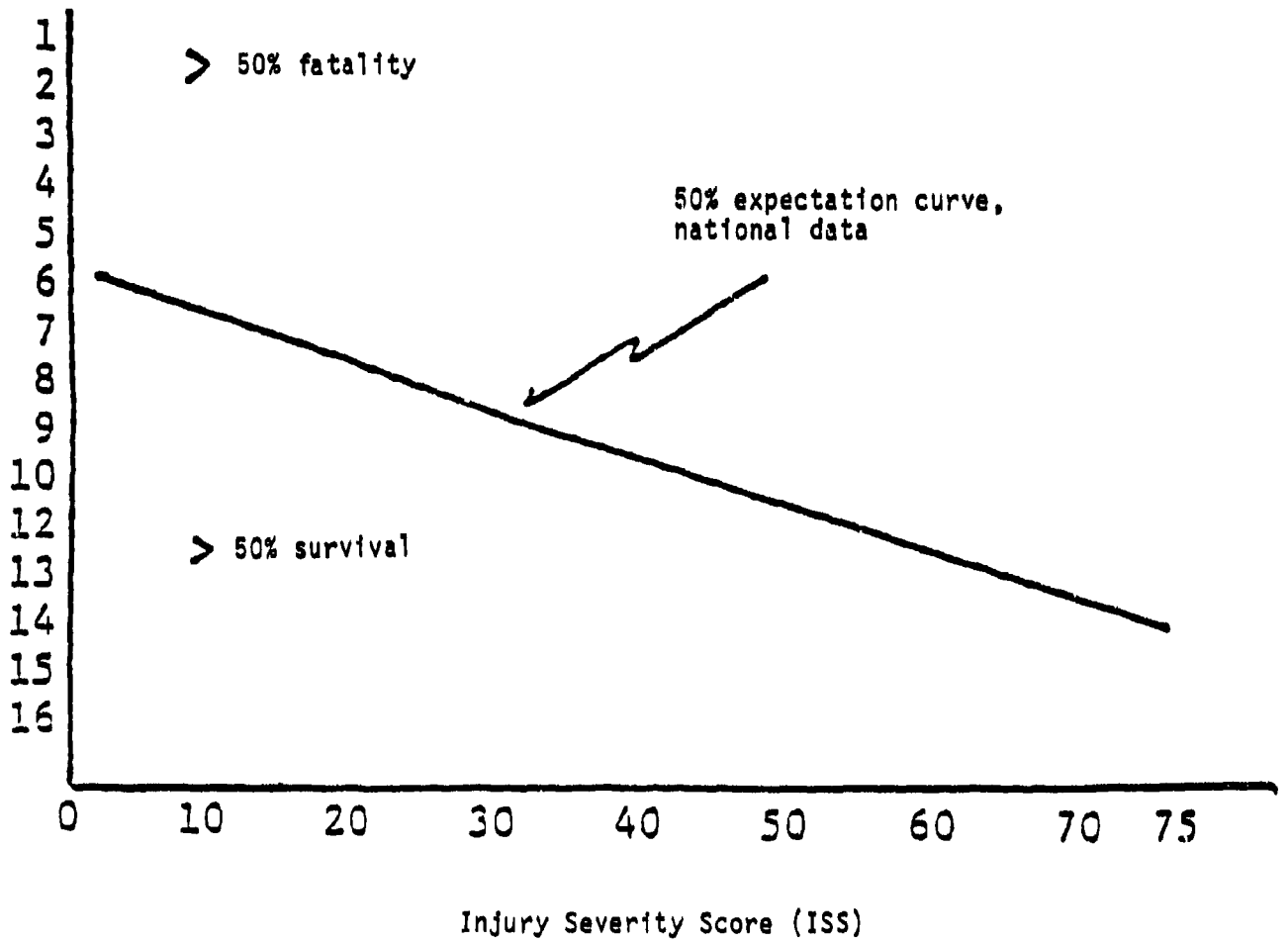

Figure 4. Relationship of TS to ISS.

The interpretation is that survivors whose TS/ISS intersection falls above the 50% expectation curve represent therapeutic triumphs; deaths whose TS/ISS intersection falls below the 50% expectation curve represent therapeutic failures; and the fraction of total casualties treated who fall in the unexpected categories reflect a level of relative excellence or substandard performance, respectively.

While these scoring systems are extremely attractive from standpoints of facilitating numerical computer entries by nonspecialists, they must accept certain harsh criticisms:

(1) Derived from civilian trauma data, they fail to account for CBR injuries. Such injuries will be among the most important to be able to assess early and accurately as regards probable outcome, with reference to expenditure of local resources, value of evacuation, and risks to health care personnel.

(2) Compilation of these scores may be either inconvenient and inaccurate, or laborious and cumbersome. For example, delaying immediate attention in order to score a victim at the scene either may be potentially dangerous, or may require presence of an additional person assigned only to scoring. The latter is unlikely in civilian EMS operations in view of both vehicle space and personnel cost limitations, it is probably impossible in military combat operations. Delaying scoring until arrival at a hospital may introduce bias toward the high side, related to patient improvement in response to care enroute; or it may cause bias toward the low side, related to tendency of transport personnel to recall "worse" than actual events at the scene knowing that, later, their performance may be judged statistically by comparison of initial scores versus outcome. Anatomic scoring has traditionally required use of extensive lists from which specific injuries present have been painstakingly selected and coded, usually at some interval after patient discharge or death. The more detailed the list of injuries, and the closer correlated with existing pathologic nomenclature, the more useful the data is for retrospective analysis of complex combat wounds (30,31), yet the more difficult it is to enter using "conventional" methods and the less useful it is for prospective decision making.

(3) The scoring systems are far from perfect in thier predictive value, from one civilian trauma center to another, of outcome following injuries apparently similar to those from which the initial data was derived. Hoping for frequent advances in quality of trauma care, it also can be anticipated that the survival curve positions will assume some plasticity for reasons other than errors in study design and data manipulation.

For several reasons, these criticisms are not sufficiently severe to warrant disregarding an otherwise promising concept:

(1) The scales can be modified, if and as necessary, to account for CBR warfare factors. To aid in this effort, use can be made of the limited data available from observations related to infrequent accidential exposure of humans to nerve agents. However, in absence of an ongoing civilian casualty experience with which to accumulate statistical significance, it will be of benefit to access animal experimental data, particularly in primates, in order to select appropriate variables and numerical values. As in other clinically relevant research, the animal laboratory can provide opportunity to control all but the independent variable(s) of interest.

(2) In contrast to "traditional" methods, the data entry process can be greatly facilitated by creation of user friendly computer programs that generate terminal screen displays of only relevant choices, and use of enhancement devices, such as physiologic and anatomic diagrams on touch screens, to expedite option selections. These techniques may be particularly attractive for entry of anatomic data; they might be sufficiently powerful to facilitate use of the highly detailed penetrating and blunt trauma scoring system (PEBL code) developed by the military for distinguishing injuries, not only to major organs and bones, but to individual nerves and blood vessels (30). However, it is likely that this degree of specificity will prove neither necessary nor useful until reaching a 3E or higher facility.

(3) Efforts currently are in progress, by national civilian medical specialty groups, to modify and update the earlier scoring systems by using pooled data from a number of nationally recognized trauma centers. If this is a successful effort, the new criteria should be significantly more accurate, and the process of revision should be established as an ongoing endeavor. Clearly the military should be able to take advantage of this information. The data is expected to be relatively valid because it will be derived in current practice with "N" values of thousands of civilian major trauma victims annually; it is expected to be recurrently updated because trauma surgeons and emergency medical physicians acting through national professional organizations will require this. Establishing ongoing relationships with selected university trauma and medical computing teams would be an obvious means by which the military could maintain regular access to the latest data, with minimum effort and cost.

(4) The concept of artificial intelligence in computing is rapidly progressing from theory to practice. Suppose it were possible to input to the same computing system, in

"real time," both the initial presenting symptoms and findings, and the short-term outcome for each casualty in a battle. Given availability of this data, it should be possible to construct a program which can, almost in "real time," update and educate itself so that the accuracy of the survival prediction curves constantly increases as the battle progresses and the data base enlarges. This information could be invaluable if faced with accumulation of casualties from a new CBR agent whose physiologic effects have not previously been "catalogued."

DEVICE-DEPENDENT MONITORING: CHOICE OF VARIABLES TO MONITOR

It has been explained why initial assessment and triage should be based predominantly upon information obtained by straightforward questioning, observations, and physical examination, with computer prompting of data collection and computer presentation of initial decision making whenever possible. Where a "device-dependent" biophysical or biochemical measurement is available, readily obtainable, relatively reliable, and potentially crucial in initial decision making, that measurement should be smoothly integrated into the (computer prompted) initial assessment routine.

Once past initial triage, treatment and longitudinal assessment must begin. Again, computer prompting of components of management and evaluation, and computer organization and interpretation of the accumulating data base, will be extremely helpful in the presence of a requirement to meet extensive casualty needs using limited personnel and other resources. In that setting, the use of computer prompted or controlled, relatively personnel independent, device-related monitoring will assume greater importance in supplementing human observations in the process of longitudinal assessment.

As previously noted, evaluation and management may often be interdependent, with the results of a measurement reflecting a problem which demands immediate attention. To the extent criteria for interventions can be based upon values of measurable variables, or upon patterns of values of several variables, computer monitoring is an ideal modality of data screening and interpretation. Computer prompting of these potentially urgent interventions, particularly in a high work-load environment such as an intensive care unit, obviously is a desirable component of the proposed computer-based data management scheme. (This concept will be expanded upon in the subsequent section on "alerts.")

In the development of device-dependent, computer-based, biophysical and biochemical parameter monitoring systems, a key

consideration is: which variables are most important (make a difference) to monitor? Attempts to determine this have been facilitated by fractionating the inquiry into several related, more directed questions: (1) Which variables are early and reliable, preferably both sensitive and specific indicators of the onset of cellular or/and organ system failure, or/and of the adequacy of resuscitation efforts? (2) Which variables are most predictive of outcome? (3) When a broad spectrum of data from multiple sources is available in computer memory, which variables do physicians and nurses most frequently recall in order to influence their clinical management decisions? Attempts to identify such "silver bullet" parameters have been met with frustrations as well as successes, as indicated in the following observations.

Early Indicators of Onset of Cellular Dysfunction and of Response to Resuscitation

With regard to which variables are early indicators of onset of, or adequacy of resuscitation from, shock states: One of the present authors has studied systemic oxygen consumption (VO_2) and interstitial fluid ion fluxes as potential indicators of the ability of cells and their membranes to sustain or regain their oxygen-dependent metabolic activities. These efforts revealed both promises and limitations of capabilities of clinically applicable, "peripheral" devices to mirror cellular functions.

A device was created with which to reliably measure VO_2 under a variety of circumstances (62-64); however, in septic shock, it was observed that other variables appeared to compensate in an apparent effort to sustain or even elevate VO_2 as long as possible (65,66). A decline in systemic VO_2 was found to be a grave prognostic sign, almost always preceded by a decline in blood pressure and other "conventionally" measurable variables.

A device was created with which to measure activity of potassium (and calcium and hydrogen) ions in interstitial fluid under clinically applicable circumstances (68-70). This tool was used to monitor potassium changes during onset of and resuscitation from hemorrhagic shock (71). While it was possible to detect chemical events in the interstitium which were "invisible" in the more conventionally monitored vascular compartment, these changes were not of a magnitude that they unequivocally would have prompted an early change in therapy.

As indicators of cellular dysfunction, both these variables are relatively specific and the latter relatively sensitive;

however, it appears that under various conditions, compensatory mechanisms prevent them from being optimal early indicators with which to influence clinical decision making at the onset of shock states. It is probably with regard to assessing response to resuscitation that the variables may be clinically most useful (66,71).

Ability to Predict Survival

With regard to which variables are most predictive of outcome: Dr. William Shoemaker, Chief of Surgery and Director of Surgical Intensive Care at Harbor General Hosptial, and editor of the Critical Care Medicine journal, has extensively studied this issue (53-61). That outcome which is least arguable, and usually easiest to study, is survival versus nonsurvival. It was found that the commonly monitored variables, i.e., blood pressure, heart rate, ventilatory rate, temperature, central venous pressure, and hemoglobin, were the poorest (individual) predictors. Derived perfusion-related variables, which correlate oxygen transport and consumption with red cell volume and flow, were among the best predictors. Next best were blood volume, blood flow, and oxygen transport and consumption, as judged by survival statistics.

It is of interest to note that similar variables, in the previously described studies by the present author, were found to be very specific but not always early indicators of impending demise. Further, in civilian practice, the general issue of outcome predictability has been challenged with regard to propriety of the implication that this information might be used as a basis for terminating care in "hopeless cases," rather than for identification of patients who might benefit from more intensive efforts (57,60). Yet, while the current level of uncertainty may prohibit this application in civilian practice, the current level of accuracy (approaching 80-90%) might constitute a strong argument for application of such "systematic" decision-making tools in combat and mass casualty situations.

Influence on Decision Making in the Intensive Care Environment

With regard to which variables are recalled to influence decision making, one of the present authors has extensive experience in designing and implementing medical computer programs in a major medical center setting (72-77). While most previous efforts have been devoted to development of computerized methods to monitor and manage the possible variables (75,76), a more recent effort was directed to study of the frequency with which components of the available data are actually used by physicians and nurses in a teaching hospital setting where

emphasis is placed on action-oriented decision making (77). For each category of data, the fraction of total recalls was compared to the fraction of total inputs. For the following broad categories of data, usage to storage ratios were as follows: combined laboratory results -- 40% of recall versus 16.3% of input; observations-- 21% of recall versus 6.8% input; drugs and fluid balances -- 22% of recall versus 36% of input; bedside monitor data --13% of recall versus 32.5% of input; all other--4% of recall versus 8.4% of input. Of particular interest is the relatively low ratio of utilization of bedside monitor data. (This study will be discussed in greater detail in the subsequent section on medical decision making in a computerized intensive care unit (ICU).) A general conclusion in this and other studies (57,60) is that choice of data to collect and store appears, to date, to have been influenced more by what is convenient than by what is important for decision making.

Choice of Variables Relevant to a 2E Facility

An attempt to optimize the choice of variables to measure and monitor in a 2E facility should be influenced not only by what is potentially important, as well as convenient, to assess in conventional medical environments, but also by what is physically possible in the battlefield environment using state-of-the-art technology. Significant constraints are imposed by potential requirements for (relatively) limited numbers of health care personnel with (relatively) minimal training to evaluate and manage (relatively) large numbers of casualties to which, particularly in the CBR warfare environment, protective clothing initially allows (relatively) restricted access in the earliest encounters. In subsequent encounters, much greater assessment opportunity is offered by the probability of personnel with (relatively) more training being able to deal with (relatively) fewer patients to which there is (relatively) "normal" access.

Data to be sought may be classified according to at least 2 kinds of priorities: (1) the degree of complexity of the acquisition process (and degree of dependency upon technique of the operator of a device); and (2) the most appropriate point in time and location at which to acquire the data (temporal and physical sequence). As previously argued, in a 2E facility as in a hospital or clinic, it generally but not always will be appropriate to seek relatively simple, device independent information first. Also as previously discussed, it is intended that information from all sources be entered into the computer data base to the maximum extent possible and as early as possible. (This concept will be expanded upon in the subsequent section on medical information bus communications.)

In ascending order of complexity, the following hierarchy is suggested: (1) data which can be acquired by an observer without monitoring devices, with exception of a hand-held "scratch pad" computer with liquid crystal display and integral memory, and possibly a blood pressure cuff; (2) data which can be acquired with simple, hand-held or portable, noninvasive monitoring devices, with minimal "technician dependence"; and (3) data whose acquisition requires more complex, less portable devices or/and invasive techniques. For each of these categories, suggestions for and explanations of appropriate data follow:

Observer with Hand-Held "Scratch Pad" Computer (and Blood Pressure Cuff)

1) Demographic and vital statistic data: casualty location, name, rank, serial number, sex, age, height, and weight (or approximations).

2) Brief past medical history: known preexisting medical problems, known medication use, and known allergies.

Note: It is suggested that the preceding 2 entries most rapidly and reliably could be accomplished by creation of a system of computer-readable dog tags upon which relevant demographic and medical data is encoded magnetically, as on credit cards, mechanically, as on some doorkey cards, or with use of laser techniques. Inserting a casualty's tag into a corresponding slot on the hand-held computer would facilitate immediate entry of this information.

3) Pulse rate and coded contour (strength and "shape"): (This is not a component of the current trauma score.)

4) Trauma score (TS) components (see Appendix A): breathing rate, coded chest expansion, systolic blood pressure (with use of cuff, but without stethoscope), coded capillary refill, and Glascow coma scale. The Glascow coma scale (Appendix A) involves assessment of level of consciousness, indexed by numerical grading of best eye opening, best verbal response, and best motor response.

Note: The TS and its component Glascow coma scale were evolved primarily in the assessment of "mechanical" injuries; however, the component responses obviously will be influenced by effects of CBR agents. It likely will be useful to augment the TS components, modify the "grading" of the existing components, or both, as possible and appropriate, in order to more accurately account for injury from CBR agents. For chemical agents,

specific modifications may be based, in part, on limited data available from review of accidental exposure of humans to nerve agents, as well as the more extensive World War I experience with mustards, phosgene, and lewisite. For reasons previously described, accuracy of scoring systems also should be enhanced by review of physiologic response data currently being obtained in primate studies.

5) Abbreviated injury scale (AIS) components (see Appendix B), to the extent specific injuries are definable, with additional attention to potential effects of CBR warfare agents: central nervous system (lethargy, impairment of breathing, motor function and coordination); eyes (conjunctivitis, blepharospasm, edema, corneal haziness); throat and lungs (hoarseness, cough, rales, dyspnea); skin (erythema, vesication); and G-I tract (vomiting, diarrhea).

Note: An observation similar to that for TS is applicable for AIS scoring; having been developed primarily for assessment of mechanical injuries, the system can be expected to be relatively insensitive to injuries by CBR agents. Modifications should be made; accuracy of modifications relative to chemical agents would be enhanced by access to primate study data; for AIS modifications the relevant data would include laboratory, x-ray, and autopsy.

6) Estimated vascular volume loss, as reflected by the following physical examination findings (11):

a. Class 1 hemorrhage: minor (0-15%) acute (fractional) loss of total circulating blood volume (TCBV) (up to 750 ml in a 70 kg adult male); minimal increase in pulse rate (normal BP, pulse pressure, breathing rate, capillary blanch-refill test).

b. Class 2 hemorrhage: moderate (20-25%) acute loss of TCBV (1000-1250 in a 70 kg male); increased pulse rate (>100), increased breathing rate (20-30).

c. Class 3 hemorrhage: major (30-35%) acute loss of TCBV (1500-1800 ml in a 70 kg male); marked increase in pulse rate (>120) and breathing rate (30-40), some decrease (if measurements can be made) in systolic blood pressure (<100) and urine output (<0.5 ml/kg/h), cool pale skin with delayed capillary refill, mental anxiety, and confusion.

d. Class 4 hemorrhage: extreme (40-50%) acute loss of TCBV (2000-2500 ml in a 70 kg male); marked increase in pulse rate (>140) and breathing rate (>35), marked decrease in

systolic blood pressure (<50-60 mmHg) and pulse pressure, marked decrease in urine output (possible anuria), cool pale skin with marked delay in capillary refill, marked mental confusion and lethargy or frank loss of consciousness.

Note: An important implication of early estimation of vascular volume loss is guidance of immediate intravenous fluid resuscitation therapy. Class 1 and 2 hemorrhage usually can be treated by infusion only of crystalloid solution, using a rule of 3 volumes of salt solution for each volume of blood lost. Resuscitation from class 3 and 4 hemorrhage usually should start with crystalloid solution using the 3 for 1 volume replacement rule, but almost always will require red blood cell replacement as guided by hematocrit and hemoglobin measurements.

7) Comfort level of patient; also coded or free text entry of comments related to preexisting ailments, and to problems for which specific diagnoses have not yet been attached.

Data Acquisition with Simple, Hand-Held or Portable, Noninvasive Monitoring Devices, with Minimal "Technician Dependence"

1) Systemic blood pressure, systolic and diastolic: blood pressure cuff, stethoscope (could use "Dynamap" automated acquisition and recording system).

2) Temperature: thermally reactive chemical tape versus electric thermometer (for continuous "core" temperature, an electric rectal or pulmonary artery catheter thermometer is needed).

3) Cardiac rate, rhythm, injury: electrocardiogram (ECG), telemetered or/and coded, with computer interpretation.

4) Peripheral gas analysis: transcutaneous tensions of oxygen, carbon dioxide ($PtcO_2$, $PtcCO_2$), hemoglobin saturation (sat tcHb); or transconjunctival tension of oxygen ($PcjO_2$): cutaneous (ear or finger) or conjunctival gas analysis and oximetry.

Note: A key question in transcutaneous gas monitoring has been whether the transcutaneously measured gas tension is an accurate reflection of the arterial gas tension, and under what conditions and to what extent that relationship may vary (78-89). Convenient parameters to study have been the

transcutaneous to systemic (arterial) gas tension ratios: $PtcO_2/PaO_2$ and $PtcCO_2/PaCO_2$. In the extensive experience in transcutaneous monitoring in neonates, that ratio remains close to 1, presumably due to the small distance between surface and core blood flow, an immature peripheral vasoregulatory mechanism, and the ability to maintain a constant ambient temperature in an isolette. In adults, this ratio has been found to vary with clinical conditions. When blood flow is normal, $PtcO_2$ changes with oxygen content (PaO_2); with hyperoxemia the ratio may be well above .9; with normoxemia the ratio may be as low as .8. When blood flow is below normal, but PaO_2 is adequate, $PtcO_2$ changes with flow. Since transport = flow x content, when either blood flow, or oxygen content, or both are compromised, $PtcO_2$ changes with transport. Thus $PtcO_2$ will track PaO_2 unless blood flow is impaired (80,82,87). The same has been shown for conjunctival measurements (91,92).

Since oxygen transport is of more important predictive value than PaO_2 (57-59), then the potential of significant divergence of $PtcO_2$, $PcjO_2$ and PaO_2 values does not necessarily have to be regarded as a liability in critical care monitoring. If there is access both to arterial blood and to a blood gas analyzer, and during continuous monitoring, $PtcO_2$ significantly decreases, arterial blood can be drawn for PaO_2 determination: If PaO_2 is relatively unchanged, there has been hemodynamic deterioration; if PaO_2 has declined, there probably (also) has been pulmonary oxygenation deterioration (87).

Of further note, the transcutaneous oximetry principle recently has been expanded upon to create a device which also facilitates continuous monitoring of pulse rate and quality as well as arterial oxygen saturation-- the pulse oximeter (93). It can be anticipated that a number of additional noninvasive multiparameter measurement devices will appear in the near future; this emphasizes the importance of insuring that the data acquisition and processing system is designed so as to accommodate modular additions of new inputs as these devices become available.

5) Neuromuscular function, alert cooperative subject: hand-grip strength measurement ("Dynamometer") in uninjured upper limb (preferably nondominant).

6) Neuromuscular function, stuperous or uncooperative subject (gross indication of cholinesterase activity): peripheral nerve stimulator (battery powered, about 2 x 7 x 10 cm).

Note: Currently available commercial stimulators, used by anesthesiologists in operating rooms to evaluate depth of induced

muscle relaxation, usually incorporate 2 electrodes, separated by about 5 cm, tipped with metal spheres about 1/2 cm in diameter. It is possible (but not necessary) to enhance skin contact by application of conductive gel. While direct visualization of electrode skin contact and muscle twitch would be the most certain means of both performing and interpreting the test, the risk of exposure prior to decontamination could be reduced either by converting the stimulator electrode tips to sharp points which could pierce the sleeve, pant leg, or face mask of the protective garment, or by incorporating metal "snaps" into the sleeve, pant leg, or face mask of the garment so that electrical contact with skin could be effected without penetration.

While present response to a nerve stimulator impulse accurately assesses the present level of neuromuscular function, it may not predict the future. That is, a casualty who arrives with twitch response present might progress to apnea with further absorption of cholinesterase inhibitor to which there was prior exposure; while a casualty who has minimal or no twitch response on arrival might recover if ventilation is temporarily supported. Predictability would be important as regards patient triage and use of limited medical resources. It would be important to know whether or not absence or marked depression of twitch response on arrival represents an accurate indicator of low probability of recovery regardless of supportive measures, and whether or not presence of normal twitch at some interval after exposure represents relative safety. These data might be obtained by appropriate additions to the protocols of primate studies currently underway.

7) Peripheral blood flow to questionably perfused limbs: Doppler probe.

8) Presence and symmetry of breath sounds, presence of bowel sounds: stethoscope.

9) Pupillary response as indicator of brainstem or systemic impairment: flashlight.

10) Measure of ventilatory strength: tidal volume, vital capacity by "respirometer"; negative inspiratory pressure (NIP) by "NIP meter."

Data Acquisition with More Complex, Less Portable Devices, Invasive Techniques, or/and More "Technician Dependence"

1) Blood gas analysis (high priority): vascular access, plus automated benchtop in vitro or in vivo sensor, with computer data link and interpretation.

2) Hematocrit and hemoglobin (immediate effects of mechanical injury, plus ongoing hemorrhage), and white blood cell and platelet counts (late effects of chemical injury, plus bleeding): automated benchtop hematology analyzer, with computer data link and interpretation.

3) Blood electrolytes ($Na, K, HCO_3, Ca, Mg, PO_4$), metabolites (lactate, glucose, creatinine, blood urea nitrogen, bilirubin); and key enzymes (amylase, CPK isoenzyme, SGOT, SGPT, GGPT, alkaline phosphatase): automated benchtop whole blood chemistry analyzer, with computer data link and interpretation.

4) Urinalysis (including specific gravity, osmolarity, urinary urea nitrogen, creatinine, urinary electrolytes): automated benchtop urinalysis device, with computer data link and interpretation.

5) Coagulation (including PT, PTT, TT, fibrinogen, fibrin split products): automated benchtop coagulation profile analysis device, with computer data link and interpretation.

6) Plain film radiographs, to include, at minimum, ability to image the chest, cervical spine, major long bones, pelvis, and skull; with computer data link and ability to digitalize images for transmission and remote interpretation.

Note: Efforts are currently underway by the Medical Operations Branch, Johnson Space Center, NASA, to select or design, and then flight rate, apparatus to accomplish all of these functions aboard space station, within a space station health maintenance facility (HMF). Both of the present authors are members of NASA's HMF planning consultation committee (one is the chairman), and are providing direct input regarding space station applicable medical devices and data management. All definitions should be completed by 1987, with flight-rated hardware appearing by the end of this decade. The weight-volume-power constraints applicable to space station HMF should be compatible with a 2E battlefield medical facility. Unless (or until) such compatibility is seen to be unlikely, it is recommended that the computerized medical decision-making process for the 2E facility plan to take advantage of the technology evolving for space station.

7) Evaluation for presence of hemoperitoneum in blunt abdominal trauma: diagnostic peritoneal lavage (relatively invasive, operator dependent).

8) Evaluation of chemical impairment of nerve function: automated benchtop serum or whole blood cholinesterase enzyme activity assay device.

Note: It might be possible to incorporate this test into an additional "channel" in a whole blood electrolyte/chemistry analyzer; otherwise this is one test that probably would be worth separate engineering effort to "package" state-of-the-art chemical laboratory analysis technique in a "field-rated" benchtop unit.

9) Evaluation of brain cortex and brainstem function: auditory brainstem evoked response (ABER). This evaluation involves application of earphones with which to deliver the "evoking" auditory stimulus, and 2 to 4 scalp electrodes with which to detect the evoked response of the auditory cortex.

10) Evaluation of brain cortex function: electroencephalogram (EEG), using as few as 4 scalp electrodes, with computer analysis of "compressed spectral array," in order to identify "spectral edge shift" and "power bands."

Note: Previous electroencephalographic techniques have enjoyed limited application in early screening for degree of injury because of requirement for meticulous placement of many delicate electrodes and relatively lengthy recording interval, hypersensitivity to patient agitation, drug effects, or hypothermia, and inability of most physicians (including most neurologists and neurosurgeons) meaningfully to interpret the results without assistance of a "mystic" specializing in electroencephalography.

The ABER test can be done with few electrodes and relatively modest equipment in a relatively brief time period, is quite insensitive to drug effect, and can produce a yes-no answer as regards functional continuity of a relatively small brainstem-cortex region. At Hermann Hospital in Houston, probably receiving the largest volume of closed head injury patients of any single hospital in the United States, the ABER study has become a screening procedure of choice to decide whether or not it is an appropriate time to perform a radioisotope scan brain blood flow study to confirm brain death. A "flat" ABER response almost invariably predicts a "no flow" scan.

The new computer compressed spectral array and power band analysis techniques have markedly improved the "image" of electroencephalography. What was a lengthy (usually many hours after a study) process of "voodoo" as regards interpretation has been reduced to on-line science by computer analysis. The equipment likely would require modification to become "field rated."

11) Evaluation of cellular function in shock states, with particular interest in detecting onset of and monitoring efficacy of resuscitation from shock: interstitial fluid ion analysis with ion selective electrodes of about 1-mm diameter, capable of percutaneous insertion (relatively invasive, operator dependent).

As previously noted, one of the current authors is engaged in laboratory shock research involving use of prototype ion sensitive electrodes; preliminary findings suggest that the interstitial fluid compartment may reveal early changes which are effectively "invisible" by intermittent ex vivo or even continuous in vivo monitoring of the vascular compartment (71). Work is currently underway to evaluate percutaneous insertion techniques, with intent to follow with human studies in the intensive care unit environment.

12) Monitor of oxygen consumption (VO_2) and carbon dioxide production (VCO_2): metabolic gas monitor.

As previously noted, one of the current authors has directed laboratory and human shock (65,66) and nutrition (67) studies using a feedback controlled benchtop autoanalyzer device to continuously measure VO_2, VCO_2, and respiratory quotient (RQ), and to compute substrate use in grams/minute of carbohydrate, fat, and protein. These parameters are fundamental indices of cellular activity; they are markedly altered in some stages of shock states; it is likely that CBR agents also might have specific and possibly dramatic effects. While currently commercially available metabolic gas monitoring units probably would be judged less than field rated, efforts are underway to select or create a similar device which will be flight rated for space station HMF. As previously suggested, it is recommended that, depending upon the resulting hardware, the 2E facility take advantage of this technology. Also, as previously noted, accurate computer decision making, relative to chemically induced changes in VO_2, VCO_2, and derived variables, will require access to primate research data.

13) Continuous systemic and pulmonary arterial blood pressure, flows: peripheral arterial and central venous insertion of arterial and pulmonary artery (Swan-Ganz) catheters (invasive; placement dependent upon operator technique).

When and Where To Acquire the Data

The second method of categorizing data to be sought relates to temporal and physical sequencing and prioritization.

Definition of optimum sequence may be influenced less by what is medically logical under "standard" circumstances, than by what is physically likely with respect to possible and probable relative locations of: (1) casualties with injuries of varying magnitudes, (2) health care workers with capabilities of varying skill levels, and (3) diagnostic and therapeutic tools of varying complexities. These relative locations could be determined by need to conform to a preexisting "physical plant" design, or the design could be driven by consideration of a preferred casualty flow pattern. The latter would be preferable for better medical care.

It is probably safe to generalize that data which is relatively device and operator independent will be sought before data which is more device and operator dependent. A goal of maximum modularity, independence, and portability for each device will maximize versatility as regards applicability in a greater number of locations and circumstances. However, final decisions must necessarily await definition of casualty flow patterns, which in turn will be strongly influenced by structural design of the 2E facility.

CASUALTY FLOW PATTERNS: RELATIONSHIP TO 2E FACILITY DESIGN

It is possible that under certain conditions, particularly those associated with novel or clandestine forms of CBR warfare, a 2E facility could be used as a point of screening for injuries not yet detected by otherwise apparently still fit combatants. The concept to be developed does not exclude that function. However, for this discussion, it will be assumed that most personnel presenting for evaluation and management at a 2E facility are presumed to have some injury (at least until determined otherwise), and most personnel without apparent injury will not seek entry into the system.

It is anticipated that the 2E facility will be expected to accomplish initial triage, decontamination as required, initial evaluation, preliminary management of injuries (often not independent activities, as previously discussed), physiologic monitoring and ongoing care, and effectuation of appropriate disposition. To do so with optimum efficiency and effectiveness, it will be necessary that decision-making logic be able to account for all of the following: (1) classification of patients according to condition upon arrival (triage); (2) potential need to eliminate or reduce residual risk from CBR agents during the evaluation process (decontamination and its influence upon triage); (3) possible and probable casualty flow

patterns within the facility (assignments to level of care), and the need to be able to move from one decision branch to another when error in prior medical judgment, based on less complete data, is discovered (internal options and error correction); (4) patient flow after release or transfer from the 2E facility (disposition options); and (5) influence of the physical design of the facility upon efficacy of delivery of care (structural compatibility). Each of these issues will be addressed.

Triage

Personnel presenting to a 2E facility initially may be classified according to at least 2 kinds of priorities: (1) the apparent immediacy of threat to life posed by their injuries, or (2) the apparent amount of assistance and intensity of effort required to treat their injuries. Although often coincident, these priorities often may not be. For example, a fractured femur may represent minimal threat to life, yet require moderate effort to treat; airway obstruction or external hemorrhage may represent immediate threat to life, yet require minimal effort to treat.

Initial sorting according to apparent immediacy of threat to life has proved useful in early management of civilian mass casualty incidents, where the ratio of immediately available health care workers to injured is very low, and the goal is survival of the largest number of casualties. Categories described, colors of tags used to identify patients assigned, and definitions of conditions are as follows: (1) "minimal" (green tag): minimal and non-life-threatening injuries; (2) "delayed" (yellow tag): injuries, even serious, whose care can be delayed temporarily because they are not immediately life threatening; (3) "immediate" (red tag): injuries likely to cause death unless treated immediately; and (4) "expectant" (black tag): injuries likely to result in death even if treated.

Although "geometry" of the disaster scene often dictates triage and staging, when conditions permit, one of the most efficient and effective methods is as follows: (1) a triage officer is positioned at the entrance to a staging area; (2) available health care workers are positioned in 3 groups according to level of ability; (3) all casualties are "tagged" as they enter the area, according to level of injury; and (4) all tags of a corresponding color are delivered to the same group of health care workers to treat and/or observe until more definitive aid and/or evacuation is available. This concept probably will be useful in prioritizing admission when relatively large numbers of casualties simultaneously arrive at a 2E facility with relatively minimal staffing.

Once "admitted," decision must be made to direct the patient to the appropriate level of care required. As previously noted, this concept often but not always will correspond to apparent imminency of threat to life. Options here are as follows: (1) no aid or self aid only required; (2) minimal but assisted aid required; (3) moderate aid required but without need for intensive care environment; (4) intensive care environment required; and (5) expected to die with or without care. When relatively small numbers of casualties arrive at a 2E facility which has relatively adequate staffing, care decisions can be made upon arrival of each casualty. When large numbers of casualties initially have been sorted into immediate, delayed, minimal, and expectant categories upon arrival, admission and assignment to level of care obviously must proceed from those categories in that order.

Decontamination and Its Influence upon Triage

As previously noted, faced with constant potential of CBR warfare, one of the key components of system design must be to prevent or reduce danger, first to still uninjured health care workers, and then to combat casualties, from lingering contamination. To insure maximum versatility and generality, it must be assumed that casualties may present with "conventional" penetrating or/and blunt trauma, in addition to chemical, biological, or radiological injury, rather than simply with one insult or the other. Whereas the CBR damage may represent the longer term threat to everyone's life, the penetrating or/and blunt injuries may represent the most immediate threat to an individual patient's life. Accurate evaluation of either threat may be impossible if the casualty presents in a chemically resistant protective garment. The removal of the protective garment may be essential for thorough evaluation and definitive treatment; however, ill-timed and ill-effected removal may expose both patient and subsequent health care workers to (avoidable) CBR injury, as well as aggravate other not yet identified injuries the patient may have.

Faced with potentially serious consequences related to either delay or haste in obtaining adequate visualization and access, the following points are important: (1) Initial triage may have to be performed prior to removal of protective garments, with limited visualization of and access to casualties. (2) To the extent possible, diagnostic devices should be adapted to existing protective garments or/and the garments should be modified to accommodate diagnostic devices in order to increase accuracy of early assessment. (3) Decision for requirement for decontamination should be made early in the evaluation process. (4) Procedures for decontamination should be developed as integral components of casualty medical

evaluation protocols, to assure accounting for situations where a casualty is unable to aid in the process, where early life support measures may be required, and where certain manipulations may aggravate coexisting injuries of a non-CBR nature.

To avoid confusion, it will probably be helpful conceptually and functionally to divide the 2E facility area into forward "dirty" and rearward "clean" zones. The "line" separating these zones is an obvious location for decontamination procedures. When a CBR threat is "ambient" (e.g., airborne residual), the clean zone will probably consist of (preferably several) CBR hardened shelters; the decontamination points will probably be located within extended entrances to these shelters.

Internal Options and Error Correction

It has been pointed out that (1) priority of admission to the 2E facility will be strongly influenced by apparent immediacy of threat to life; (2) assignment of level of care will be influenced by apparent intensity of care required to treat apparent injuries; and (3) these initial decisions may often be made with a scant preliminary data base. It can be anticipated that judgment errors, related to inadequate early information, will be common. Therefore, within the decision algorithms for each degree of urgency category and each level of care "track," there must be incorporated mechanisms for changing categories and tracks. This capability is crucial not only for patient safety, but also for "operator acceptance." (If the logic frequently doesn't work, the health care workers will ignore it.)

Within each level of care track, as soon as treatment is accomplished, there must be incorporated a decision-making process as regards disposition.

Disposition Options

Once treated within a 2E facility, the following options exist: (1) discharge in ambulatory status to return directly to combatant status; (2) discharge in ambulatory or/and self care status without ability to return directly to combat ready status; (3) discharge with requirement for an interval of observation or/and holding in or near a 2E or 3E environment before final disposition; (4) evacuation, with or without care enroute, to a 3E (or larger) facility; and (5) continued care or observation within the 2E facility. The patients who require continued care or observation within the 2E facility will include those

expected to meet discharge criteria with additional time and care, those who should be evacuated with care enroute but for whom evacuation is currently unavailable, and those in the expectant category.

Structural Compatibility

If one were "starting from scratch" with casualty field evaluation and management in the CBR environment in mind, one would probably design a chemically protective combat garment different from the model currently available. However, availability of the current protective garment in units of (? tens of) thousands makes it very unlikely an optimum design, relative to casualty management, will be undertaken in the near future. The same need not be true with regard to design of the 2E facility within which casualties are treated.

While design of individual shelter buildings may become relatively aplastic, the configuration of such buildings within a 2E facility may be negotiable. If this is true, then there may exist an opportunity to configure the facility to complement a previously optimized battlefield casualty evaluation and management decision-making process, rather than assume the decision-making process must conform to a nonoptimal "physical plant."

Once again analogy may be drawn to civilian hospital operations, where confusion is presumed to be significantly less than battlefield conditions. In this (relatively) more ordered and organized environment, it has been found essential functionally if not always physically to separate emergency services, intensive care, ward care, outpatient clinic, etc. Similarly, in a 2E facility, it will be highly desirable functionally and, if possible, physically, to separate each of the following: (1) the minimal, delayed, immediate, and expectant urgency of care categories prior to "admission"; (2) the minimal, moderate, intensive, and expectant level of care tracks after admission; and (3) the self care/ambulatory, observation/holding, evacuation staging, and morgue dispositions after delivery of care.

Worst case would be a single one-room building in which all evaluation, care, and holding must be accomplished. Quality of care and safety would be compromised at all levels. Relative to use of one-room buildings, best (practical) case would be at least 4 adjacent shelters in the "clean" zone, one assigned to each care track, physically linked so as to permit "shirt sleeve" environment transfer of patients whose status subsequently is

assessed as warranting a different level of care. It is anticipated that at a typical point in time, the minimum care unit would have the most patients, relatively few health care workers, and relatively sparse needs per patient; while the intensive care unit would have fewer patients, relatively more health care workers, and relatively dense needs per patient. That distribution would approximately optimize utilization, per square foot, of several buildings of the same size.

Where relatively large numbers of casualties may need to be triaged and "staged," prior to "admission," it would be desirable to have at least 4 more shelters in the "dirty" zone, one assigned to each triage category (tag color), physically linked to allow easy transfer upon recognition of apparent change in status, and with each incorporating a decontamination capability.

Where relatively large numbers of personnel may need to be temporarily sheltered, held, observed, or staged for evacuation following treatment, it would be desirable to have at least 4 more shelters in which to accomplish the following functions: (1) temporary sheltering of ambulatory and self-care personnel (including those who will return directly to combat status); (2) observation and holding area for casualties who need short interval reevaluation but not continuous monitoring; (3) staging area for seriously injured who require relatively continuous monitoring or/and care while awaiting early evacuation, plus accommodation of ICU overflow; and (4) a temporary morgue. Where original protective garments must be redonned upon departure by ambulatory and self-care patients, the sites of post-care sheltering for these categories may need to be immediately adjacent to sites of entry in the "dirty" zone.

Diagram of 2E Casualty Management

Based on the foregoing arguments, Figures 5-7 provide a flow chart type schematic overview of suggested evaluation and management within a 2E facility. The boxes are representative of functional areas, independent of existence of structural areas to correspond. As previously stated, with requirement to process relatively large numbers of casualties, function will be optimized by adding buildings or partitions so that structural divisions correspond as closely as possible, in numbers and orientation, to functional divisions.

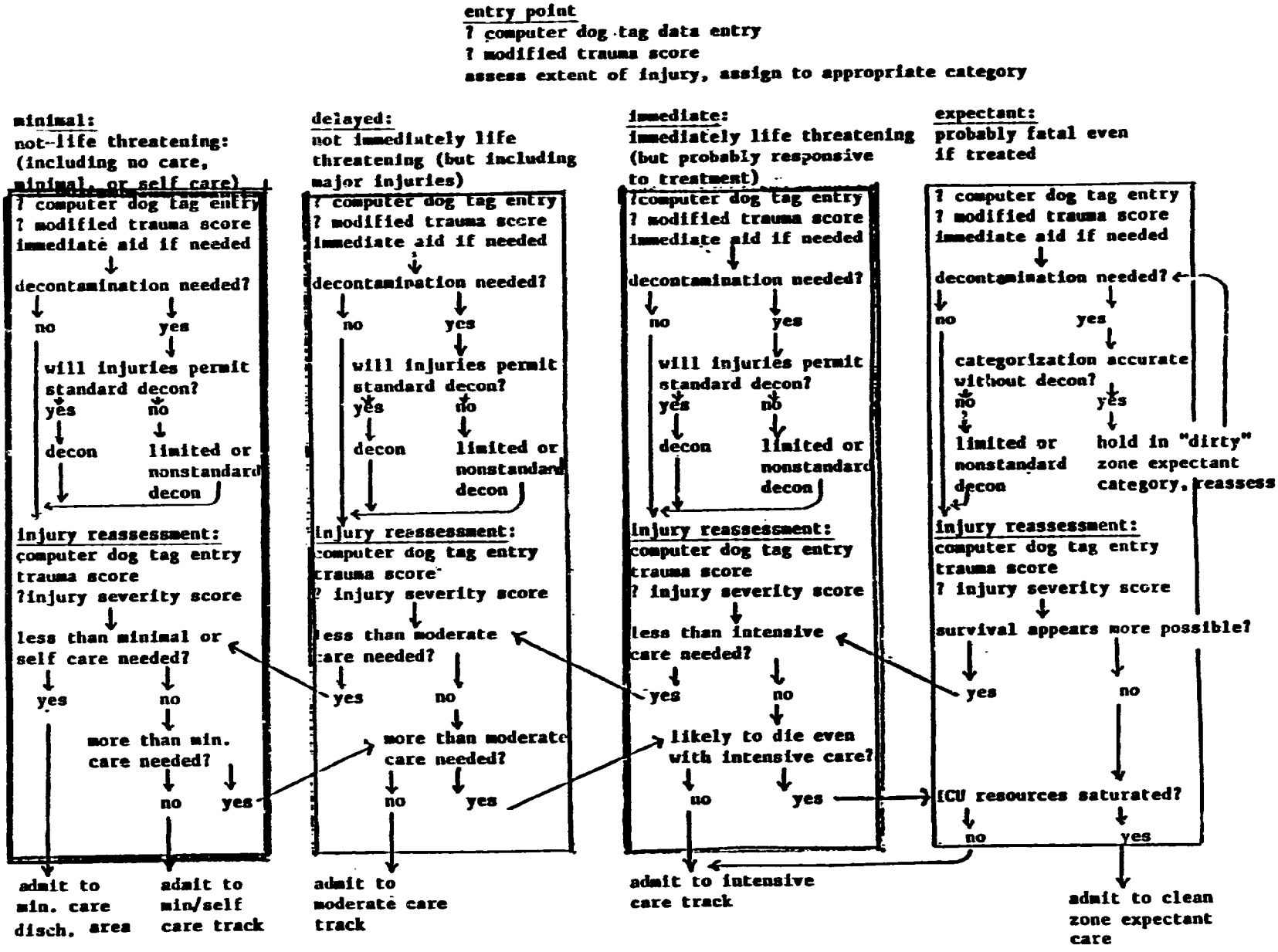

Figure 5. Initial triage (dirty zone).

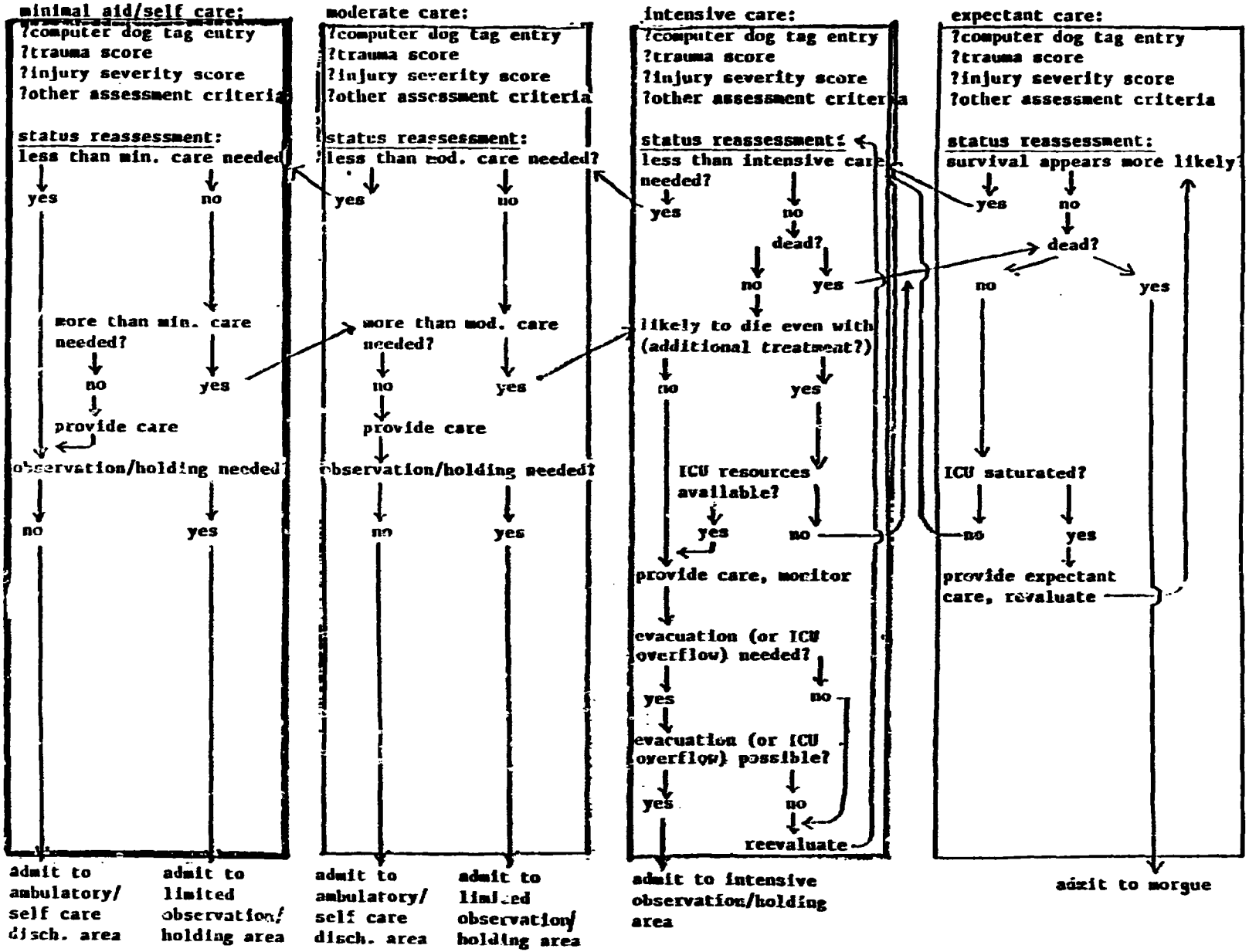

Figure 6. Initial care (clean zone).

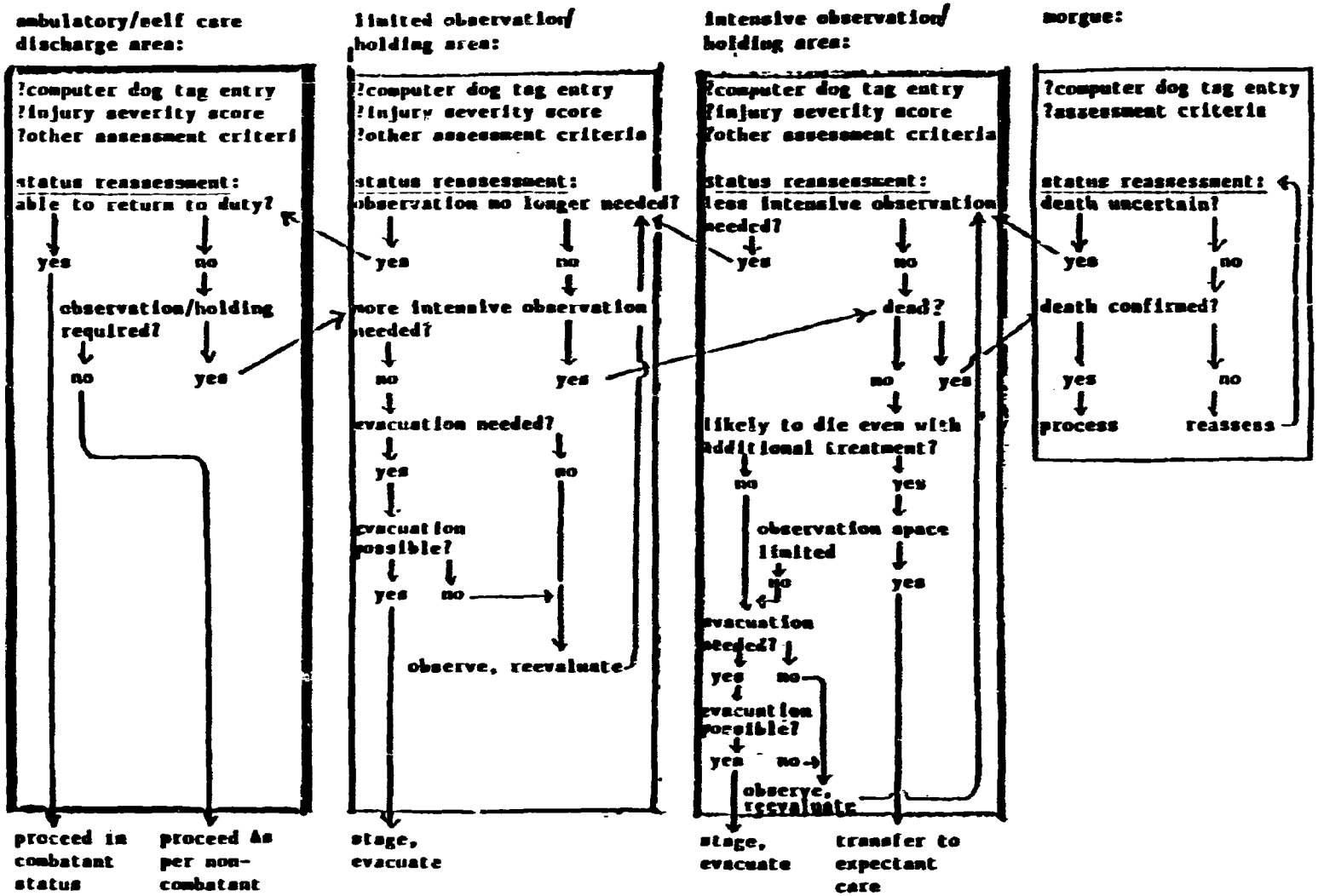

Figure 7. Disposition/observation/holding (clean area).

Yet to be addressed are the following issues: (1) When and where shall the component activities of evaluation, scoring, and monitoring be accomplished? (2) How (if at all) should scoring systems be used in the decision-making process? (3) How (if at all) can a casualty be evaluated while the casualty and quite possibly the health care worker are fully clothed in protective garments? Definitive conclusions must necessarily await better definition of the variables to be monitored, the monitoring and data management devices, and the structure of the 2E facility. It is hoped that some of these definitions will come into sharper focus during discussions subsequent to submission of this report. However, the following suggestions and observations are offered.

Possible Sequencing and Location of Data Acquisition

As previously explained, one axiom is to use simpler, less device- and technician-dependent modalities before more complex, more device- and technician-dependent methods. Exceptions include rapidly obtainable, device-related data, such as cuff systolic blood pressure, which may significantly influence decision as to immediacy of care required, and chest x-ray, which may significantly influence specificity of care required. For example, low blood pressure diagnoses shock and indicates need for immediate attention; chest x-ray diagnoses tension pneumothorax (as the probable cause of shock) and indicates the specific attention needed. Table 1 indicates possible sequencing and location of the previously described data, relative to the previously described 2E facility. Note: While precise times and locations remain to be negotiated, it is expected that it will be helpful, if trauma scoring is used, to complete that assessment upon entry into care; it will be likely, if injury severity scoring is used, to complete that assessment during or prior to release from care.

Use of Scoring Systems in Triage and Allocation of Resources

Trauma score might influence casualty assignment to initial triage category; after initial triage, TS might influence assignment to initial level of care. These assignments might be concurrently influenced by adequacy of available medical resources (personnel and supplies), and whether or not chemical agent injury is likely to be a factor influencing the score. (A casualty whose low TS probably reflects chemical impairment may have a better chance of survival, if intensively supported for an interval, than a casualty whose low TS reflects severe mechanical injuries.) The decision process might be as shown in Figure 8.

TABLE 1. POSSIBLE SEQUENCING AND LOCATION OF DATA ACQUISITION

Location	Common to all triage areas, all levels of care	Common to delayed or immediate triage, to moderate and intensive care	Related primarily or exclusively to immediate triage, intensive care
Time			
First contact	Dog tag entry		
Prior to leaving triage/assignment to care	Pulse rate, contour Trauma score Neuromuscular function (grip strength versus peripheral nerve stimulator response)		? Metabolic gas monitor
Immediately after arriving in care unit	Comfort level, other diagnoses	Estimated vascular volume loss BP Temp Doppler flow (when indicated) Stethoscope auscultation (when indicated) Pupillary response (when indicated) Visual acuity check (when indicated)	ECG Continuous oximetry Measurement of ventilatory gas analysis (when indicated)
While care underway		Hematology status (when indicated) Chemistry status (when indicated) Urinalysis (when indicated) Coagulation (when indicated) Plain film radiograph (when indicated) Peritoneal lavage (when indicated)	Cholinesterase assay ABER study EEG study Cellular function study Metabolic gas monitor
Prior to discharge from care	AIS/ISS		

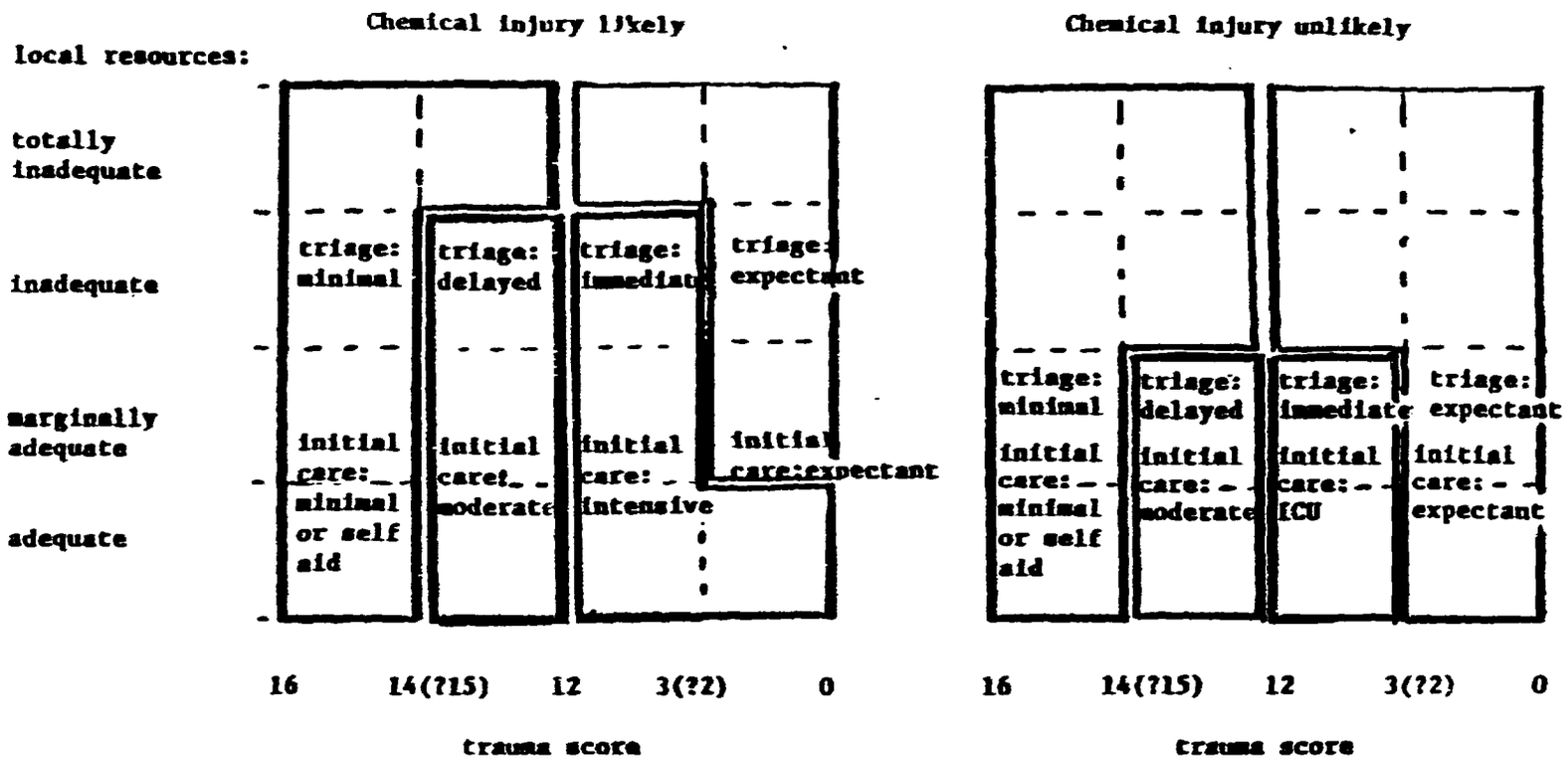

Figure 8. Potential use of trauma score to influence initial triage.

Similar decisions might be influenced by the ISS, likely, as previously noted, to be completed somewhat later than the TS. In addition to adequacy of local resources, other variables which might be weighed against severity of injury of a particular casualty are the probable total number of injured, probable average severity of injuries, possibility and probability of evacuation, and availability and usability of communications. As previously noted (section on combat (and mass disaster) triage), while it is possible graphically to represent only 3 variable axes, it is possible theoretically to ask a computer to concurrently manipulate "N" variables.

Possible Evaluation of Casualty in Protective Garment

If both a casualty's condition and local resources are sufficiently "good," optimum management in a CBR warfare environment probably would consist of decontamination and removal of protective garments as appropriate, followed by thorough evaluation. However, there are several circumstances in which ability to evaluate, with reasonable accuracy, prior to decontamination and removal of clothes, would be desirable. These include: (1) extremis of casualty condition, in the presence of adequate resources relative to needs, so that knowledge of urgency of need for support would change decisions toward immediate action; and (2) extremis of casualty condition, in absence of adequate resources relative to needs, so that knowledge of severity of injury would change decisions toward deferral of action (and, possibly, assignment to expectant category).

In the first circumstance, capability to mechanically support ventilation, <u>prior</u> to removal of protective headgear and mask, would further accentuate the value of ability to accurately assess vital functions prior to removal of protective garment. At the present time, it is the authors' understanding such capability does not exist. Efforts have included use of high frequency ventilation through the mask, without success (94).

From the list of data to be sought (section on choice of variables relevant to a 2E facility) and the comments on sequencing (section on sequencing and location of data acquisition), the following variables appear most appropriate to attempt to assess with a casualty still protectively clothed:

1) <u>Limited history and physical examination</u>: From the alert, cooperative patient, a great deal can be learned prior to removal of protective clothing. Unfortunately it is the stuporous or/and uncooperative patient who is of most concern, both as regards possibility of chemical injury and potential mechanical injuries requiring immediate attention.

2) Dog tag medical data: Acquisition of this information would require access to the tag without removal of clothing.

3) Pulse: If the pulse is relatively normal in rate and strength, a radial pulse can be palpated through the cuff of protective gloves; if the pulse is weak, it might be necessary for an examiner to slide a hand up under the protective headgear shoulder mantle to attempt to palpate the carotid pulse. The latter maneuver would be with risk of contaminating the patient's neck, and with potential failure of ability to identify a weak pulse with a (thickly) gloved examining finger. A Doppler probe examination of the wrist or neck is an alternative, also with risk of contamination.

4) Trauma score: All components of the TS could be compromised in accuracy of assessment in the fully clothed casualty with potential chemical injury. (a) In a casualty breathing normally, ventilatory rate and chest expansion could be assessed reasonably well; with shallow rapid breathing there could be significant doubt, even with palpation. In absence of other body motions, an electronic chest expansion detector might be of value. (b) Systolic BP by upper arm cuff and radial palpation would be satisfactory for measurement of relatively normal BP; there could be significant doubt for low BP. Limited exposure for a Doppler probe at the wrist might be required. (c) Capillary refill would be effectively unavailable without increased exposure. (d) All components of the Glascow coma scale would be assessible; however, as noted previously, their interpretation in the presence of chemical injury is in doubt.

5) Neuromuscular function: If distinctly abnormal, this could be a valuable guide to decision for either aggressive rapid intervention, in presence of adequate resources, or assignment to expectant category, in absence of adequate resources. For the alert, cooperative patient, the handgrip meter would be a good test. For the stuporous or uncooperative patient, the peripheral nerve stimulator would be appropriate. For the latter, as previously noted, skin contact could be made by piercing the sleeve or pant leg with sharp probes, or by incorporating metal snaps in sleeves, pant legs, or masks of protective garments.

6) Metabolic gas analysis: As previously noted, oxygen consumption and CO_2 production represent fundamental parameters of cellular function. In some settings (95), continuous monitoring of CO_2 output (capnography) has become the most central component of assessment of patient status intraoperatively under anesthesia; abnormalities may reflect CO_2 production or elimination or both. While it has not been possible to effectively mechanically ventilate via the inhalation ports of the protective combat headgear, it might nevertheless be possible to effectively collect all expired gas via the exhalation ports of the mask. This collection, plus knowledge or

measurement of fractions of oxygen and CO_2 in inspired gases, would permit generation of a capnographic record, and determination of VO_2 and VCO_2 (64,67).

MEDICAL DECISION MAKING: EVALUATION OF DATA IN A COMPUTERIZED INTENSIVE CARE UNIT

Background

Rapid evolution of noninvasive and invasive means of assessing patients' anatomic, physiologic, biochemical, and pharmacologic status has produced a state of virtual "information glut" in many major medical centers. Because of speed and information processing capabilities, computers have been increasingly employed in medicine to aid in management of this data, especially in the intensive care unit (ICU) environment, where pertinent physiologic data must be readily available to allow quick and accurate decisions on patient care in life-threatening situations. Computers in the ICU are also used in conjunction with patient monitoring equipment to analyze waveforms, calculate derived physiologic parameters, and store monitored patient data for future use.

At the Latter Day Saints (LDS) Hospital in Salt Lake City, automated data management is employed in ICUs to the extent that these units are almost completely computerized. Patient data from most sources within the ICU, and from other parts of the hospital (e.g., laboratory results, pharmacy orders) are automatically integrated into each patient's computer record. These computing capabilities have not been limited to data storage and retrieval, but have been applied to facilitate effective use of the patient data base, and to aid medical personnel in the decision-making process. Goals in these areas have included the development of an organized, concise presentation of important patient information, refinement of the computerized data base to make it as efficient as possible, and a study of the use of patient data by physicians in decision making in the ICU.

Work in these areas has been conducted mainly within the Shock-Trauma ICU at LDS Hospital. This unit's patient population consists of trauma victims (30%), patients with postoperative complications (50%), and patients with medical problems such as renal failure or cardiac arrest (20%); these problems (although in different proportions) are those likely to be encountered in a 2E medical facility treating casualties of conventional and chemical warfare. Therefore, the data management principles developed in the ICU should be applicable to the design of 2E and higher military field medical facilities.

Originally, computerized patient data was available to health care providers through a series of reports such as blood gas, laboratory, cardiac output, shift, and 7-day summary printouts. To provide a convenient, concise report of patient data, the ICU Rounds Report was developed (Fig. 9). This report is organized by organ system and is generated by the computer upon request. The report shows current values of patient data items as well as the patient's demographic information. Space has been provided to record observational data which is not available from the computer record. The report allows physicians to review a patient's status by referencing one readily available source.

Methods

With the Rounds Report in hand, a study of patient data use in physician decision making in the Shock-Trauma ICU was conducted during the period from December 1982 to October 1983. Data usage was first examined during daily physician teaching rounds in which each patient in the unit is reviewed and a care plan for the day is formulated. Preliminary data on information usage by physicians was also gathered "on site" at the bedside because it was felt the majority of physician decision making occurred in these two settings. Results of this study are expected to help optimize the computerized ICU patient data base, insure that frequently used patient data are readily available, and identify areas where further improvements in data entry and storage can be made.

Items of patient data available for use in decision making were classified into 6 data categories (Table 2). The actual use of an item was recorded either on the ICU Rounds Report in the rounds setting or on a checklist developed for physicians to use in recording patient data usage on site. For each decision-making setting, patient data items used were tabulated in the appropriate category. The category totals were then converted into their respective percent of total patient data usage.

Results

The results of the study are summarized in Figure 10 and in Table 3. Figure 10 compares the use of patient data in each of the 6 data categories in the rounds and on-site settings. Table 3 shows the average rounds and on-site results as well as the makeup of the computerized patient data base for comparison.

DATA WITHIN LAST 24 HOURS

NAME: NO. 3791951 ROOM: E411 DATE: OCT 19 09:54
DR. , ROBERT E. SEX: M AGE: 48 HEIGHT: 183 WEIGHT: 72.55 BSA: 1.94 BEE: 1649 HOF: 13
ADMIT DIAGNOSIS: PNEUMONIA ADMIT DATE: 30 SEP 85 APACHE II: 27
SURGERY:

CARDIOVASCULAR: 3 EXAM: _____

TIME	CO	CI	HR	SV	SI	VP	MSP	MP	SVR	LWI	PW	PA	PVR	RWI
OCT 19 05:00	8.60	4.45	116	74	38	8.0N	94	83	9	43	10	38	3.3	15.5

OCT 19 01:00 DOPAMINE (INTROPIN) 2.00 MCG/KG/MIN
LV PARAMETERS ARE WITHIN NORMAL LIMITS

	SP	DP	MP	HR	LACT	CPK	CPK-MB	LDH-1	LDH-2
LAST VALUES	94	60	73	108					
MAXIMUM	194	132	141	137	1.7 (05:00)	( )	( )	( )	( )
MINIMUM	85	45	55	81					

RESPIRATORY: 3

OCT 19 85		pH	PCO2	HCO3	BE	HB	CO/MT	PO2	SO2	O2CT	IO2	AVO2	VO2	C.O.	A-a	Qs/Qt	PK/	PL/PP	HR/SR
19 06:21	V	7.37	38.2	21.8	-2.8	12.9	2/ 1	42	72	13.0	45						0/	0/ 5	14/ 0
19 05:20	A	7.41	38.8	23.1	-.5	12.8	3/ 1	73	92	16.7	45	3.72			152	28	0/	0/ 5	14/ 0

NORMAL O2 SATURATION AND PO2
MILDLY REDUCED O2 CONTENT
NORMAL ARTERIAL ACID-BASE CHEMISTRY
SAMPLE # 60, TEMP 38.8, BREATHING STATUS : ASSIST/CONTROL

19 23:31	V	7.40	35.9	22.0	-1.7	12.2	2/ 1	40	73	12.4	45						0/	0/ 5	14/ 0
19 23:30	A	7.42	33.2	21.3	-1.7	12.5	2/ 1	69	92	16.1	45	3.37			160	29	0/	0/ 5	14/ 0
19 20:38	V	7.41	34.0	21.3	-1.9	13.4	2/ 1	38	69	12.8	45						0/	0/ 5	14/ 0
19 20:38	A	7.48	30.4	21.5	-.5	13.2	3/ 1	83	94	17.5	45	5.04			160	18	0/	0/ 5	14/ 0
19 13:48	V	7.39	38.4	22.4	-1.8	11.4	2/ 1	37	72	11.5	40						40/	30/ 5	18/ 0
19 13:48	A	7.42	32.9	21.1	-1.9	11.3	3/ 1	69	93	14.8	40	3.38			131	24	40/	30/ 5	18/ 0

10/19/85	VENT MODE	VR	VT	O2%	PF	TEMP	PK	PL	PP	e-VT	c-VT	s-VT	MR	SR	TR	M-VE	S-VE	tot VE	COMP	EAR-OX	OX	CUFF P	CF
19 08:40	S-I A/C	15	900	45	65	37.0	42	36	8	960	790		16			12.5			28.2				5.0
19 07:25	S-I A/C	15	900	45	65	37.0	41	32	8	1010	845		18			15.2			35.2			18	5.0

19 07:25 35525/ 10/07:30 INTERFACE: NASOTRACH; ALARMS CHECKED; TEMP SETTING: 5.0; POSITION: FOWLER; PATIENT CONDITION: APPREHENSIVE;

19 07:15 35525/ 15/07:27 -RESPIRATORY PARAMETERS-

	HR	RR	VT	VC	VE	MIP	MEP	MVV	PK FLOW
	112	48	370		17.0	-41			

POSITION: FOWLER; PATIENT CONDITION: RESTLESS, UNCOOPERATIVE; POSITION: FOWLER;

19 05:15	S-I A/C	14	900	45	65	37.0	40	29	5	1035	860		18			15.5			35.8				5.0
19 05:05	S-I A/C	14	900	45	65	37.0	40	18	5	1035	860		18			15.5			78.2				5.0
19 04:10	S-I A/C	14	900	45	65	37.0	41	30	5	1050	870		29			25.2			34.8				5.0

19 04:10 44741/ 15/05:09 INTERFACE: NASOTRACH; BREATH SOUNDS: IMPROVED; ALARMS CHECKED; TEMP SETTING: 4.5; POSITION: FOWLER; PATIENT CONDITION: CALM; SUCTIONED, 6 CC, GREEN, PURULENT, THICK;

10/19/85 03:45 -MEDICATION NEBULIZER (IN-LINE)- -CPT-
PATIENT INTERFACE: IN LINE WITH VENT; POSITION: FOWLER; MEDICATION: ALUPENT, 10 MG, DILUENT: NORMAL SALINE; PRE BREATH SOUNDS: BRONCHIAL, RLL LATERAL, RML; MECHANICAL PERCUSSION: FOR 15 MIN, TRENDELENBURG/RIGHT, TRENDELENBURG/LEFT, BLL; COUGH: WHEN ENCOURAGED, MODERATE, PRODUCTIVE; SPUTUM: SUCTIONED, 4 CC, YELLOW, GREEN, THICK; PATIENT CONDITION: ALERT, COOPERATIVE; POST BREATH SOUNDS: UNCHANGED; COMMENT: RX TOL WELL;
HEART RATE: 114/ /118 RESP RATE: 20/ /

19 02:20	S-I A/C	14	900	45	65	37.0	46	31	5	1025	820		25			20.5			31.5				5.0

NEURO AND PSYCH: 0
GLASCOW 14 (06:00) VERBAL _____ EYELIDS _____ MOTOR _____ PUPILS _____ SENSORY _____

OTR _____ BABIN. _____ ICP _____ PSYCH _____

COAGULATION: 2
PT: 13.3 (06:00) PTT: 53 (05:00) PLATELETS: 80 (05:00) FIBRINOGEN: ( ) EXAM: _____
FSP-CON: ( ) FSP-PT: ( ) 3P: ( )

RENAL, FLUIDS, LYTES: 2

IN	4858	CRYST	3800	COLLOID	378	BLOOD	275	NG/PO	30	NA	131	(05:00)	K	4.5	(06:00)	CL	100	(05:00)	
OUT	4834	URINE	1788	NGOUT	815	DRAINS	138	OTHER	1830	CO2	21.8	(06:00)	BUN	29	(06:00)	CRE	2.7	(05:00)	
NET	25	WT	72.55	WT-CHG	.45	S.G.	1.014			AGAP	13.9		UOSM			UNA		CRCL	

METABOLIC — NUTRITION: 0

KCAL	2580	GLU	193	(06:00)	ALB	( )		CA	( )		PE	( )		TIBC	( )				
KCAL/KG	512	UUN	( )		N-BAL	.0		PO4	( )		MG	( )		CHOL	( )				

Figure 9. LDS hospital ICU rounds report (1 of 2).

GI, LIVER, AND PANCREAS: 0 EXAM:

HCT	33.7 [08:00]	TOTAL BILI	[16:35]	SGOT	[16:35]	ALKPO4	[16:35]	GGT	[16:35]		
GUAIAC	[ ]	DIRECT BILI	[16:35]	SGPT	[16:35]	LDH	498 [16:35]	AMYLASE	88 [23:45]		

INFECTION: 3

WBC 23.3 [05:00] TEMP 38.3 [16:00] DIFF 52B, 33P, 14L, 1M, E [05:00] GRAM STAIN: SPUTUM _____ OTHER _____

SKIN AND EXTREMITIES:

PULSES _____ RASH _____ DECUBITI _____

TUBES:

VEN _____ ART _____ SG _____ NG _____ FOLEY _____ ET _____ TRACH _____ DRAIN _____

CHEST _____ RECTAL _____ JEJUNAL _____ DIALYSIS _____ OTHER _____

MEDICATIONS:

MORPHINE, INJ	MGM	IV	13	POTASSIUM CHLORIDE, INJ	MEQ	IV	40
ACETAMINOPHEN, SUPP	MGM	RECT	650	CALCIUM GLUCONATE, INJ	MEQ	IV	9.200
CEFOPERAZONE [CEFOBID], INJ	MGM	IV	3002	MAGNESIUM SULFATE, INJ	MEQ	IV	16
PIPERACILLIN [PIPRACIL], INJ	GM	IV	8	SODIUM ACETATE, INJ	MEQ	IV	50
AMPHOTERICIN B, INJ	MGM	IV	66	POTASSIUM PHOSPHATE, INJ	MM	IV	10
DOPAMINE, INJ	MGM	IV	420	TRACE ELEMENTS, INJ	ML	IV	1.600
METAPROTERENOL [ALUPENT], SOLUTION	MGM	INHAL	50	NA PHOSPHATE, INJ	MEQ	IV	16
FUROSEMIDE, INJ	MGM	IV	20	POTASSIUM ACETATE, INJ	MEQ	IV	40
HEPARIN, INJ	UNITS	IV	2000	ELECTROLYTE VOLUME	ML	IV	10.200
HEPARIN FLUSH	UNITS	IV	400	INSULIN REGULAR, INJ	UNITS	IV	30
HEPARIN, INJ	UNITS	SUBQ	10000	INSULIN REGULAR, INJ	UNITS	SUBQ	7
METHYLPREDNISOLONE [A-METHPRED], INJ	MGM	IV	15	MVI-12 , INJ	ML	IV	13.200
SODIUM CHLORIDE, INJ	MEQ	IV	20				

**********MICROBIOLOGY**********

-ROUTINE CULT- **-PRELIMINARY REPORT-** 18OCT 10:50
SOURCE: SPUTUM
STAIN: NUMEROUS GRAM NEGATIVE BACILLI, MODERATE NUMBER OF GRAM POSITIVE COCCI, FEW GRAM POSITIVE BACILLI, NUMEROUS WBCS.

-ARO BLOOD CULTURE- **-PRELIMINARY REPORT-** 18OCT 08:20
[SPECIMEN COMMENT]: SEE PRINTED LAB REPORT FOR COMMENTS
SOURCE: BLOOD, ARM RIGHT

-ARO BLOOD CULTURE- **-PRELIMINARY REPORT-** 18OCT 08:15
[SPECIMEN COMMENT]: SEE PRINTED LAB REPORT FOR COMMENTS
SOURCE: BLOOD,

-ROUTINE CULT- **-FINAL REPORT-** 17OCT 10:00 COMPLETED 19OCT85
SOURCE: URINE, CATHETERIZED
RESULT: NO GROWTH IN 48 HOURS.

-ROUTINE CULT- **-PRELIMINARY REPORT-** 17OCT 10:00
[SPECIMEN COMMENT]: SEE PRINTED LAB REPORT FOR COMMENTS
SOURCE: URINE, CATHETERIZED

-ARO BLOOD CULTURE- **-PRELIMINARY REPORT-** 17OCT 09:55
[SPECIMEN COMMENT]: SEE PRINTED LAB REPORT FOR COMMENTS
SOURCE: BLOOD,

**********X-RAY SECTION**********

*** CHEST RESULTS ***

DAY	
16	NO CHANGE, ASPIRATION/PNEUMONIA=

*** CT RESULTS ***

16	SEE DICTATED REPORT=

*** END OF REPORT ***

Figure 9. LDS hospital ICU rounds report (2 of 2).

TABLE 2. PATIENT DATA CATEGORIES

1.	Bedside monitor	Heart rate, blood pressures, cardiac output, cardiac rhythm, respiratory rate, temperature
2.	Laboratory	Electrolytes, white count, differential, cultures, coagulation, lactate, enzymes, drug levels, hematocrit-hemoglobin, metabolic/ nitrogen balance
3.	Blood gas	pH, PCO_2, HCO_3, BE Hb, COHb, PO_2, $SatO_2$, O_2 content, FIO_2, AVO_2 diff, venous O_2 A-a gradient Qs/Qt
4.	Drugs input/output	Medications, intravenous feeding, fluid balance, urine output, energy balance
5.	Observations	Cardiac examination, respiratory parameters (weaning), neuro-psych, weight, weight change, GI examination, gram stains, skins and extremities
6.	Other	History, ECG, X-rays, EEG, CT scan, etc.

TABLE 3. PATIENT DATA USE STUDY RESULTS

	Lab	Drugs Input/ Output & IV	Observa- tions	Bedside monitor	Blood gas lab	Other
A. Average % of data used on rounds 121 patients evaluations	31.5	23	21	12.5	9.5	2.5
B. % of data used on site (35 decisions Oct. 83)	18	13	22	22	20	5
C. % Change in data usage	-13.5	-10	+1	+9.5	+10.5	+2.5
D. % of data in computer record	8.5	36	6.8	32.5	7.8	8.4

Discussion

In analysis of the computerized patient data base, the goal was to find areas in which the relative volume of data stored was much greater or less than the indicated usage in decision making, determine any other pertinent factors which should be taken into consideration, and decide upon improvements which could be made to facilitate best use of available resources relative to not storing too much or too little information in any one "area."

Patient data from the combined laboratory (laboratory and blood gas laboratory) categories made up 38 to 40% of the patient data base used both in rounds and on site, while occupying only 16.3% of the computerized data base. These results indicate the importance of having reliable laboratory data readily and easily available to clinicians for decision making.

In the drug, input/output, and IV category, data storage exceeded data usage by 13% (rounds) to 23% (on site). Reduction of the amount of data stored in this area is desirable, but somewhat limited by long-term and legal storage requirements. Technology is available, and is being implemented at LDS Hospital, to make most data entry in this category occur automatically without human intervention. Automatic entry is particularly desirable in view of the large amount of data that is involved (36% of computer data base).

The amount of data usage in both the rounds and on-site settings for the observations category was about the same (21-22%). Comparison of data usage with data storage for this category shows a favorable ratio: it makes up only 6.8% of the computerized data base. However, much of the observational data used by physicians in decision making is not currently entered into the computer record. Therefore, more entries from the observations category will be added to the computer data base, with intent to develop a method for easy data entry.

Data from the bedside monitor made up 32.5% of the computerized patient data base, while accounting for between 12.5% (rounds) and 22% (on site) of the data used in decision making. These results, although not discounting the importance of the bedside monitor in reflecting the current hemodynamic status of a patient at bedside, pose a question of how much of the information originating from the bedside monitor is really useful after the fact. Since monitoring equipment may well represent the most costly component in equipping an ICU (or 2E facility), it is important to evaluate which physiologic parameters must be monitored for effective patient care, and to have monitors capable of transmitting their physiologic data to a computerized central file where it can be selectively stored and

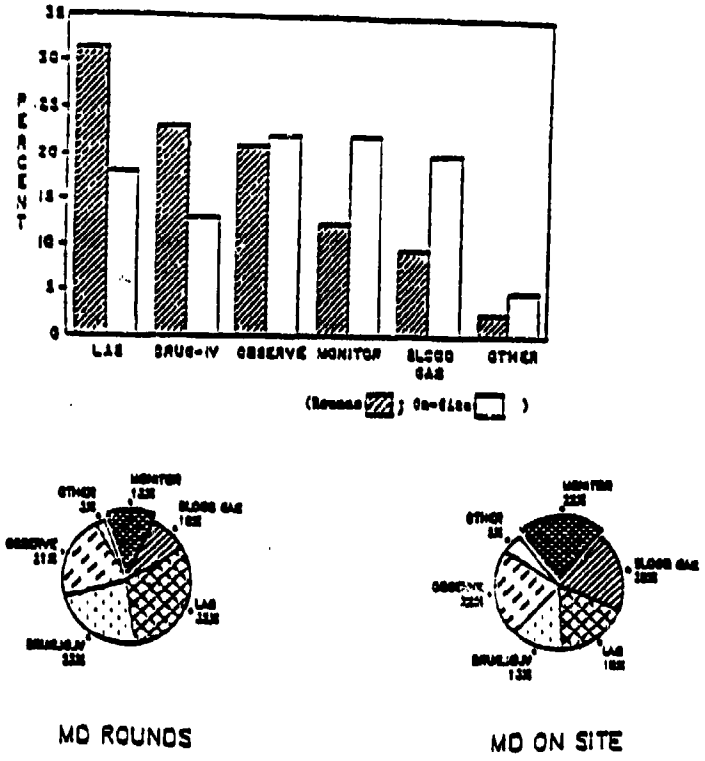

Figure 10. ICU patient data use.

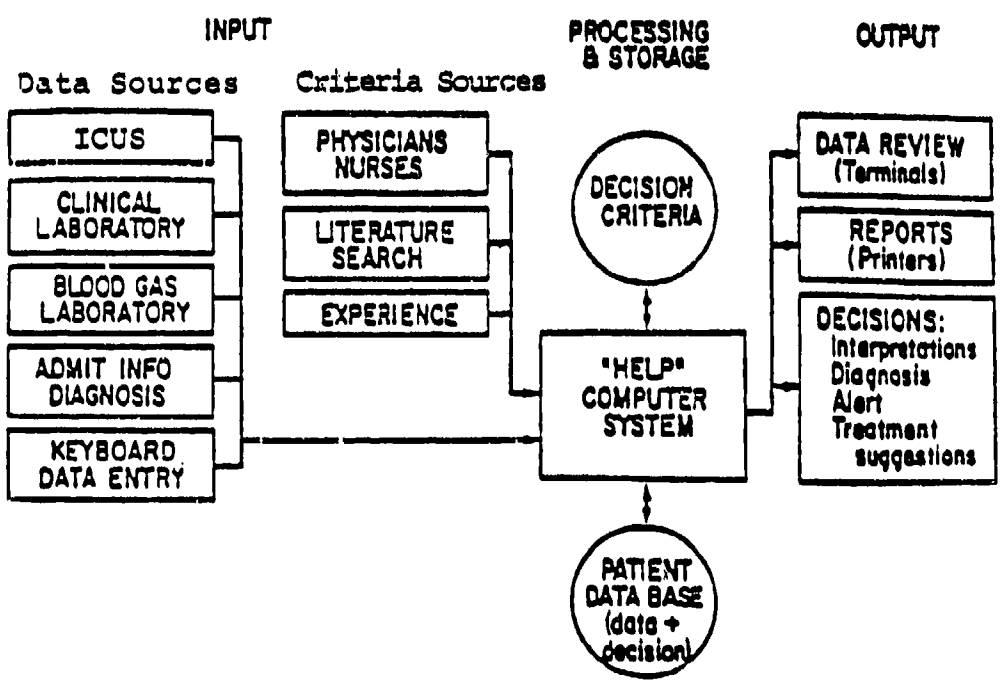

Figure 11. HELP system block diagram.

combined with other information in an optimized data base. Along with use of the ICU Rounds Report so that the most important items of patient information are readily and rapidly available, the computerized integration of the data base allows the physician to get an overall picture of patient status with a minimum of time and effort, and facilitates effective medical decision making.

The Concept of Alerts: The HELP System

Under a National Center for Health Sciences Research (NCHSR) grant for developing applications of computerized protocols in medicine, a series of criteria were established for the existence of life-threatening situations in hospital patients. These criteria were used to implement an alerting system (96) based on the HELP decision-making computer system (97-99) at LDS Hospital. These alerts provide prompt and accurate reporting of life-threatening conditions to medical personnel so that corrective measures can be implemented within a shorter time frame. In this way, the interval during which a patient's life is potentially threatened is reduced. Other types of alerts have also been implemented in the hospital, including pharmacy alerts to flag drug-drug and drug-laboratory interactions.

The HELP computer system has a flexible categorizing and decision-making capability, and is able to evaluate data within specific time constraints. The system takes data from many sources and processes the data to determine if specified decision criteria are met. Figure 11 shows a system block diagram of HELP. Data is processed by executing decision modules which are stored on magnetic disk. The decision modules contain the decision criteria for the life-threatening situations. On evaluation, those decision modules which are true (i.e., the life-threatening condition exists) generate alert "flags"; these are both recorded in the patient's file, and are brought to the attention of those caring for the patient.

Another feature of HELP which is useful for alerts is the fact that evaluation decision modules may be data driven; that is, the decision modules are automatically evaluated without human intervention whenever the specific item of patient data which "drives" the decision module is entered into the patient record. Alerts then can be generated automatically by the computer, and the computer automatically checks the patient file for data which indicates the presence of whatever condition is being screened for by the particular HELP decision module. The alerting system has been further extended so that simple treatment-oriented protocols, giving suggestions on treatment of the patient's condition, are generated along with the alert, and

made available to nurses and physicians. These protocols were developed in consultation with medical specialists, and from information presented in the medical literature.

In an evaluation of the effect of the alerting system on patient care, it was found that some alerts, such as that for metabolic acidosis, cause a dramatic change in physician behavior and result in more rapid and appropriate treatment, as well as a quicker recovery by the patient from the life-threatening condition. A training effect was also observed, so that over time, physicians became more aware of the possibility of the life-threatening condition and began to respond more rapidly and appropriately on their own. A second group of alerts (e.g., hematocrit falling) produced minor changes in physician response, and a final group (e.g., low hematocrit) produced no changes in patient care.

While some alerts have been found to be useful throughout the hospital, as both the intensity of care and the ratio of health care providers to patients decreases in transitioning from ICUs to general care wards, the alerts assume an increasingly important role in patient care, despite the fact that a larger number of alerts are generated for ICU patients. A nurse or physician caring for a large number of patients is less able to personally check on every life-threatening possibility for every patient. For this reason, it is suggested that an alerting system would be particularly beneficial in the 2E medical facility, in which it is likely that a (relatively) small number of health care providers will be required to take care of a (relatively) large number of critically ill patients within a (relatively) hectic environment.

It is envisioned that implementation of an alerting system in a 2E facility would be similar to that at the LDS Hospital, with a main processing unit running a modified HELP system, using alert decision modules modeled on those already developed. However, it likely would be beneficial to expand the number and types of alerts in order to address the spectrum of probable life-threatening conditions which may occur in patients with injuries of conventional and/or CBR warfare types. Alerts generated by the system could then be displayed on the individual patient's terminal, on the main display terminal along with alerts on other patients, and in the patient's computerized record for later review and use in decision making.

Action-Oriented Decisions

A natural extension of the alerting system for life-threatening conditions is the development of computerized action-oriented decision protocols. In the original alerting system, simple treatment protocols giving some possible treatment suggestions were generated along with the alerts. These protocols can be expanded so the computer follows preprogrammed logic which automatically conducts a search of the record for other pertinent data, or requests the health care provider to supply necessary data, which then allows the computer to give specific treatment suggestions based on what it has found to be the most probable underlying cause of the alert condition.

This process can be illustrated with an example based on the hypokalemia alert. The original alert criteria specified that if:

1) potassium serum level is less than 2.2 mEq/L; or
2) potassium serum level is less than 3.3 mEq/L in the presence of acidosis (blood pH < 7.3); or
3) potassium serum level is less than 3.0 mEq/L and the patient is receiving digitalis concurrently;

then the patient has HYPOKALEMIA. Along with the alert, the alerting potassium value was listed, and the following suggestions were given:

1) Rule out laboratory error
   CONSIDER:
2) Stop K+ excreting diuretics
3) Control severe diarrhea

Using the same alerting criteria, it is then possible to do a flow diagram of the computer logic which could be implemented so that the computer carries out the decision-making logic to determine which of the possible treatments is most appropriate, and then, along with the alert, provides suggested treatment to the nurse or physician (Fig. 12). The implementation of this logic on the computer can thus aid the health care provider in the decision-making process by automatically considering many possibilities, some of which may not be immediately obvious, without requiring time-consuming research into the medical literature or the patient's record by the physician, and yet still allow the provider to make the final decision as to whether to follow the computer's suggestion or to override it due to other mitigating circumstances.

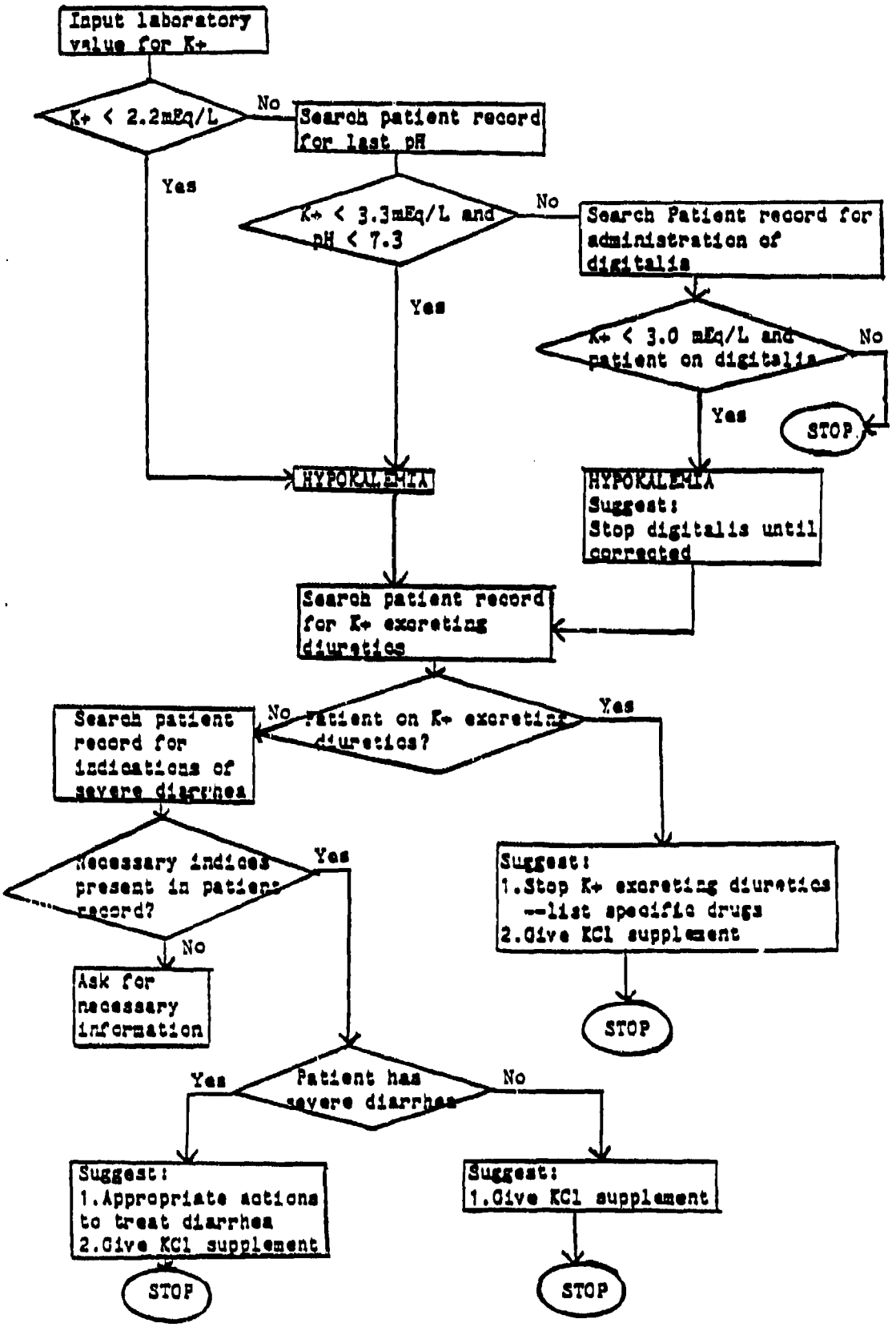

Figure 12. Example of an action-oriented decision: hypokalemia.

COMPUTER HARDWARE "PERIPHERALS" CONSIDERATIONS

The Concept of a Medical Information Bus

The key to obtaining maximum potential benefit from the HELP and the alert systems is the concept of an integrated data base which is updated as soon as possible after a relevant piece of information or data point becomes available. Accomplishing the latter is facilitated by direct linkage, with a central data base processor, of as many human and device dependent data gathering points as possible. This linkage constitutes a medical information bus (MIB). It is important in systems development that description of the MIB be specified as a component of the initial design phase, in order to accomplish compatibility and standardization.

A goal of MIB design is the creation of a communications system which will allow many medical devices to "talk" with a computer system. Figure 13 illustrates, in a schematic form, how the MIB might be connected to a seriously ill patient. Data can come from or be sent to devices such as IV pumps, urine output measuring devices, fluid drainage devices, ventilators, and other support devices. Thus, it will be possible to get data promptly and efficiently in even the most difficult situations.

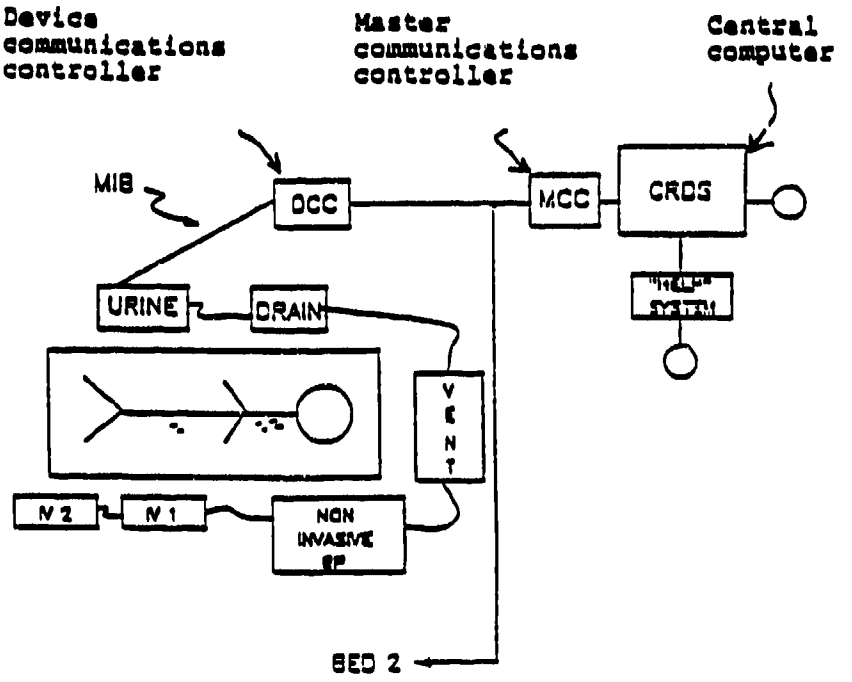

Figure 13. Diagram of medical information bus (MIB).

An MIB communications protocol will allow an expanding number of microprocessor-based bedside devices to be used for data acquisition. In the future, closed loop control will be both feasible and a practical clinical tool. The MIB concept will allow implementation of this type of technology.

Figure 14 indicates how labor might be shared between a bedside "scratch pad" computer and a central processor unit. The bedside computer should be a small data collection and display device. This computer should contain within it data collection algorithms and memory to store the data. In the more complex situation where data from invasive and noninvasive sensors are available, the sensors should interface to the scratch pad computer to capture appropriate data. The scratch pad computer should have sufficient capability to direct data collection algorithms and validate the data before transmission to the central processor. Transmission to the central processor could be carried out digitally using error detection and correction techniques over wire or radio communication links.

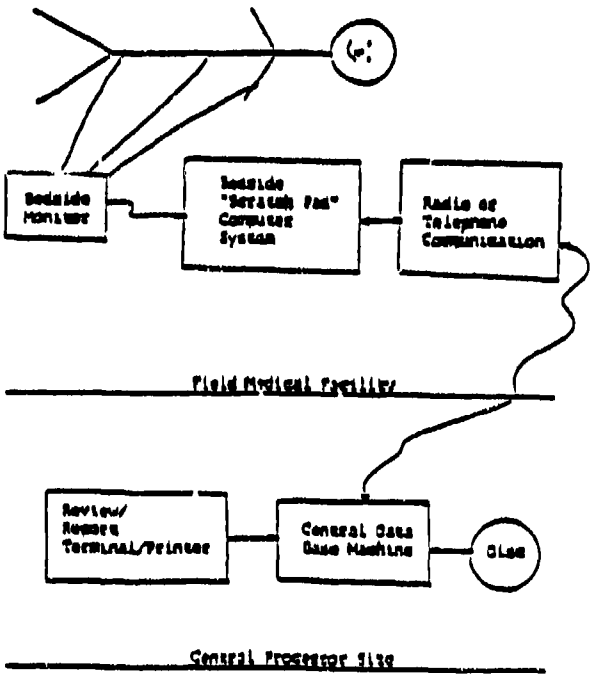

Figure 14. Relationship of bedside "scratch pad" computer to central data base machine.

While the bedside unit should have simple diagnostic and therapeutic decision criteria contained within it, the central processor should supervise the overall medical decision-making process. Both systems should work in concert to suggest "action oriented" decisions for health care providers within the 2E facility. Typical of data presentation which might be available from the central site to a health care provider is a report similar to the rounds report previously described (Fig. 9). The central data base also can be used as an accounting mechanism for medical resource management. For example, whenever a drug is administered or a unit of intravenous fluid infused, the computer can subtract it from inventory; hence, a remote commander can audit remaining supplies in real time.

The Issue of Vulnerability to Electromagnetic Pulse

With proposal to introduce any magnetic material based computer system into a modern battlefield environment, several questions need to be raised: (1) What is the vulnerability of the system to destruction or disablement by an electromagnetic pulse (EMP)? (2) What are the consequences of loss of the computer system to future operations dependent upon it? (3) What are potential countermeasures to blunt those consequences? Suggested answers to these questions are discussed in the following paragraphs:

While actual vulnerability to EMP, of a variety of commercially available magnetic based memory systems, is probably unknown and probably dependent on strength and duration of pulse, for planning purposes it must be assumed that memory of a battlefield computer system could be significantly disrupted by an insult which might not concurrently annihilate all potential users. Thus EMP should be considered a "real" problem, even if, statistically, it is likely that an insult which eliminates computer memory will also eliminate the users.

Absence of satisfactory defense against loss of the computer system to EMP should not be considered sufficient argument to invalidate the proposed concept, just as vulnerability of sophisticated and (otherwise) effective weapons systems does not prevent their acquisition. For most forms of warfare, EMP is not an issue. If the medical computer system were lost in mid battle for any reason, a great deal of value would have been gained and would be retained due to the educational aspects of its use to that time. This "on-line" teaching modality, previously described, may prove to be of benefit equal to the monitoring capabilities.

Fortunately, there probably is an effective countermeasure to EMP, at least as regards protection and reproduction of key

software and memory. What is proposed is that core logic and memory be "permanently" recorded in LASER disc units. If the magnetically based units become scrambled by (transient) EMP, their memory could be reestablished, after the insult has passed, by instructions provided by LASER disc references. Other optically based, although less "information dense," methods are available for EMP resistant data storage.

CONCLUSIONS

Battlefield Conditions

A modern battlefield may pose challenging and adverse conditions as regards initial evaluation and early (1) careful sequencing of data acquisition so that maximum information is obtained by simple straightforward means before use of more complicated, device- or technician-dependent studies; (2) increasing use of quantitative scoring systems with which to grade severity and predict outcome of critical illness and injury; and (3) increasing use of computers for data acquisition and management. Some negative features in such centers include the following: (1) inadequate attention to the issue of mass casualty triage, in which it is necessary to prioritize patients as well as injuries; and (2) historical "evolution" of most medical center computing systems without attention to smooth central integration of all data inputs so as to maximize potential decision-making capabilities.

Lessons, Adaptations from Major Medical Centers

Given these "conditions of practice," it will be advantageous to design a system for casualty management which provides maximum decision-making assistance to 2E facility health care workers. In that design, whenever possible, advantage should be taken of decision-making algorithms and management processes evolved at major civilian medical centers engaged in the regular care of large volumes of critically ill and injured patients. Key positive features in the function of such centers include the following: (1) careful sequencing of data acquisition so that maximum information is obtained by simple straightforward means before use of more complicated, device- or technician-dependent studies; (2) increasing use of quantitative scoring systems with which to grade severity and predict outcome of critical illness and injury; and (3) increasing use of computers for data acquisition and management. Some negative features in such centers include the following: (1) inadequate attention to the issue of mass casualty triage, in which it is necessary to prioritize patients

as well as injuries; and (2) historical "evolution" of most medical center computing systems without attention to smooth central integration of all data inputs so as to maximize potential decision-making capabilities.

Choice and Classification of Data

In describing information to be sought and variables to be monitored in a 2E facility, the following classification, according to ascending order of complexity, appears convenient: (1) data which can be acquired by an observer without monitoring devices, with exception of a hand-held "scratch pad" computer with liquid crystal display and integral memory, and possibly a blood pressure cuff; (2) data which can be acquired with simple, hand-held or portable, noninvasive monitoring devices, with minimal "technician dependence"; and (3) data whose acquisition requires more complex, less portable devices or/and invasive techniques. While no single parameter has proven both highly sensitive and specific as regards early indication of onset of a significant shock state, several clinically applicable techniques are rapidly emerging that provide a much closer reflection of cellular function, particularly as regards response to resuscitation. In major medical centers, more attention is being paid to identifying variables which are important, rather than only convenient, to monitor. Technology to be developed in the near future in conjunction with NASA's space station health maintenance facility may make available "field rated" devices with which to obtain a full spectrum of desirable data under combat conditions.

Potential Use of Injury Scoring Schemes

The trauma score and the injury severity score currently appear to be the most promising of injury scoring schemes proposed and in use. The former involves assessment of physiologic status, using simple criteria, before specific injuries are known. The latter involves the grading of specific injuries, in different anatomic regions, as these become identified. Both scores appear to have better outcome predictive value at the extremes rather than centers of their scales; neither score is designed to accurately account for effects of CBR warfare injuries.

Computer-Assisted Medical Decision Making

Major medical center intensive care units currently are finding that their major problem is not so much how to

acquire patient data, but rather how to effectively manage and use it. There is a virtual information glut. Those in the forefront of medical computing today are directing an increasing amount of their attention to the issue of computer-assisted medical decision making. Key components of that effort are the following: (1) selection of appropriate variables to store and manipulate, and determination of appropriate amounts of memory to devote to storage of particular data relative to demonstrated amounts of recall and use; (2) design of systems which accomplish automatic entry of desirable data from as many points of origin as possible so as to maximize information available for decision making; (3) construction of data evaluation processes and decision-making algorithms which parallel those of the best physicians and which are automatically initiated or driven by arrival of new data; and (4) generation of "alert" messages which, based on current and past data patterns, draw attention to undesirable patient conditions, provide possible differential diagnoses, and offer suggestions for confirmation and correction. An overall goal is to make available the decision-making process of an excellent physician on a good day to an average health care worker on a bad day. The "HELP system," in use at the LDS Hospital in Salt Lake City, probably represents the best effort to date to achieve maximum integration of automated medical data acquisition and use.

Consideration of Casualty Flow and Facility Design

Decisions related to data acquisition in a 2E facility must be influenced not only by what is important and possible to measure, but by where and when measurements should and can be made relative to the flow pattern of casualties. Data will be lost or ignored if the intended acquisition and use processes are not compatible with the realities of patient flow. Therefore, the system should be designed to account for the following potential needs: (1) initial triage, wherein large numbers of patients arriving within a short time interval may need to be first "sorted" according to apparent immediacy of threat to life posed by apparent injuries; (2) decontamination, prior to which some decisions may have to be made despite very limited access to some patients for physical examination; (3) assignments to appropriate levels of care, based largely on estimations of intensity of effort required to treat apparent injuries; (4) corrections of errors in triage and assignments to levels of care, introduced by incomplete initial data and changes in patient condition; and (5) patient dispositions at completion of care in the 2E facility. Relative to these needs, data acquisition processes and decision making algorithms could be greatly enhanced by initially

designing the 2E facility to be structurally compatible with the mission which it is expected to accomplish.

RECOMMENDATIONS

Longitudinal Relationships with University Medical Centers

In the medical technology research and development business, university medical centers exhibit certain unique and advantageous characteristics. The medical centers not only conceptualize and prototype, but also are end users of new apparatus and techniques. This process is in contrast, for example, to university engineering departments that usually do not use products they conceptualize and to typical community hospitals that usually do not design the products they use. In the development of bioengineering devices and medical computing systems, the university medical center environment is not only that of think tank, but also of immediate proving ground. Device and data management system development is an ongoing process. With exception of the military during an active conflict, neither the military nor corporations maintain comparable experience with or are able to devote comparable resources to concurrent study of trauma management, critical care decision-making, and medical computing, on a regular basis. An advantage of establishing ongoing relationships with medical educational institutions which are engaged in these activities would be that advances in knowledge, apparatus, and techniques could be translated into military applications on a continuing, real-time basis.

Modular System Components

Insofar as possible, system components should be kept modular, so as to facilitate easy substitution or addition of better ideas, apparatus, and techniques as they appear. This concept applies to hardware and software, with particular emphasis on monitoring devices and "micro" computer equipment. As just noted, one way the military could access new concepts in trauma management, critical care monitoring, and medical computing would be to establish ongoing relationships with university medical centers involved in these activities.

Selection of Data To Be Sought, Variables To Be Monitored

Divided according to relative complexity, and device and technician dependence, the following information gathering is

suggested:

Data acquisition by observer with hand-held "scratch pad" computer (and blood pressure cuff):

1) Computer dog tag entry of demographic and vital statistic data

2) Computer dog tag entry of past medical history

3) Pulse rate and coded contour

4) Trauma score components

5) Abbreviated injury scale components

6) Estimated (physical exam) vascular volume loss

7) Comfort level; coded or free text list of complaints, comments

Data acquisition with simple, hand-held or portable, non-invasive monitoring devices, with minimal "technician dependence":

1) Cuff and stethoscope measurement of blood pressure

2) Chemically reactive tape or electric thermometer measurement of temperature

3) Cardiac rate, rhythm, and injury analysis by ECG

4) Cutaneous or conjunctival gas analysis and oximetry

5) Hand grip strength measurement of neuromuscular function, alert cooperative subject

6) Peripheral nerve stimulator assessment of neuromuscular function, stuperous or uncooperative subject

7) Doppler probe assessment of blood flow to questionably perfused limbs

8) Stethoscope assessment of presence and symmetry of breath and bowel sounds

9) Flashlight assessment of pupillary response

10) Respirometer measurement of ventilatory volumes; negative inspiratory pressure (NIP) meter measurement of ventilatory strength

Data acquisition with more complex, less portable devices, invasive techniques, or/and more "technician dependence":

1) Blood gas analyzer measurement of oxygenation, ventilation, acid-base parameters

2) Automated hematology analyzer measurement of red cell, white cell, and platelet values

3) Automated whole blood chemistry analyzer measurement of key electrolytes, metabolites, and enzymes

4) Automated urinalysis device measurement of urine specific gravity, osmolarity, urea nitrogen, creatinine, electrolytes

5) Automated coagulation profile measurement, to include PT, PTT, TT, fibrinogen, fibrin split products

6) Plain film radiographs, to include chest, C-spine, skull, pelvis, long bones

7) Diagnostic peritoneal lavage to assess hemoperitoneum in blunt trauma

8) Automated benchtop serum or whole blood cholinesterase enzyme activity assay device

9) Auditory brainstem evoked response (ABER) measurement of brain cortex and brainstem function

10) EEG using computer analysis of "compressed spectral array" to evaluate brain cortex function

11) Percutaneously insertable ion selective electrode measurement of interstitial ion (K+, Ca++) activities as reflection of cellular membrane function in shock

12) Metabolic gas monitor (MGM) measurement of oxygen consumption, CO_2 production, and substrate (carbohydrate, protein, fat) utilization as indicator of integrity of cellular metabolic function in shock

13) Swan-Ganz catheter measurement of cardiac filling pressures; thermodilution determination of cardiac output

Most of this data currently can be obtained with commercially available devices; for that which cannot be, technology is rapidly emerging which likely will accomplish the desired measurements. Field rating of this equipment also is a consideration. It is anticipated that an important driving force in these regards may be requirements of NASA's space station health maintenance facility; it is recommended that the military take advantage of that technology, as it develops, by establishing ongoing relationships with those involved in those efforts. Other new methods and techniques relevant to 2E facility monitoring are likely to appear first in university medical centers involved in trauma management, critical care, and medical computing. An effective way to access these developments probably would be to establish ongoing relationships with such centers.

Use of Scoring Systems in Decision-Making Logic

Potential advantages of developing scoring system methodology appear to outweigh the disadvantages. The best of the existing scoring systems should be modified to account for effects of CBR warfare agents. These modifications should be based upon both limited data from human exposures to nerve and other chemical agents, and upon data from animal studies, including primate studies at the Southwest Foundation for Research. When appropriate data otherwise would not evolve from those studies, study protocols should be modified so as to provide the relevant information. Efforts should be directed to creation of user-friendly computer programs that generate terminal screen displays which expedite data entry, including physiologic and anatomic diagrams on touch screens. Maximum advantage should be taken of efforts now underway nationally

to improve the accuracy of existing scoring systems through assessment of pooled current data contributed by a number of major civilian trauma centers. A conceptualization study should be undertaken to investigate potential applicability of artificial intelligence techniques to the construction of a program which could generate, in real time during a several day battle, ability to predict outcome versus initial symptoms and findings for a new CBR warfare agent whose characteristics are unknown at the onset of the battle.

These efforts would benefit from input from individuals with involvement in trauma management, critical care, and medical computing; a means by which to acquire this input would be to establish ongoing relationships with university medical centers involved in these activities.

Maximizing Use of Appropriate Computer Technology

It is recommended that appropriate computer technology be used where and whenever possible to assist battlefield 2E facility health care workers, with relatively minimal medical specialty background, perform their duties in an environment of high stress, workload, confusion, and risk. This effort should begin with modifications and programming of a hand-held, "scratch pad" computer with which to accomplish initial screening data entry, including information directly from a dog tag, and extend to development of a central computer system, managing data for the entire 2E facility via medical information buses and utilizing the "HELP system" concept for decision making and suggestions for interventions. In addition to functioning as a highly efficient data input and management tool, the computer system also should be programmed to function as a teaching aid for medical personnel, and to permit battlefield commanders, by electronically (hence "invisibly") changing certain baseline assumptions of medical resources versus needs, to influence casualty disposition decisions reached by 2E medical personnel at remote sites.

Given recent and anticipated rapid advances in the state-of-the-art of commercially available hardware, the military should concentrate its medical computing development efforts primarily upon software rather than hardware. Programs should be developed with intent, at any arbitrary point in time, to rapidly adapt them to the best commercially available equipment at that time. "Field rating" of devices is a consideration, but one which should be subordinate to remaining flexible enough to be able to take advantage of the anticipated frequent and favorable changes in weight, size, power requirements, and networking capabilities of new equipment.

One means by which to develop the necessary medical computing logic and software, and to select the appropriate computer hardware with which to prototype the suggested systems, would be to establish ongoing relationships with university medical centers involved in trauma, intensive care, and medical computing.

Design of 2E Facility to be Compatible with Mission

Insofar as possible, the 2E facility should be configured structurally to facilitate accomplishment of the mission it is expected to perform. The decision-making logic system and the physical plant should be designed to account for triage, decontamination, assignments to appropriate levels of care, corrections of errors in triage and assignments to levels of care, and patient dispositions. If possible, chemical protective garments also should be designed with consideration given to initial evaluation and management of injuries to the wearers. Input should be obtained from medical personnel regularly involved in trauma management and critical care delivery.

Establishing Clinical "Test Sites" and Training Centers

It will be of value to designate clinical test sites at which to evaluate efficacy of new monitoring devices, scoring systems, and data management and decision-making logic. Among options for such sites are busy intensive care units in civilian trauma centers; a way for the military to access this environment would be to establish ongoing relationships with selected university surgical departments and medical computing departments.

Beyond need to evaluate individual components of the proposed system, there would be significant value in being able to continuously work with, reevaluate, and update the entire system in an operational patient care environment. From a standpoint of peacetime evaluation and revision of the trauma and critical care management protocols, maximum benefit would be derived from having the system operational in a major civilian teaching hospital oriented to trauma and intensive care. From a standpoint of peacetime education and (re)training of military personnel who are potential users "in the field," maximum benefit might be derived from having the system operational in a major military teaching hospital or by contracting for rotation of military personnel through teaching experiences at appropriately equipped civilian teaching hospital(s).

Engineering history is replete with examples of good ideas in theory which failed in practice because of minor glitches which were unforeseen short of operational application. Military history teaches similar lessons which are the justification for expenditure of extensive resources for the purpose of repeated training exercises in peacetime. Planning for combat casualty management deserves but apparently has not received the same attention with respect to regular "rehearsal." For some "acts" of medical management, however, there is an absolute requirement for real patients if real lessons are to be learned and maximum training achieved.

For these reasons it is recommended that there be developed, in a military and/or a major civilian trauma/critical care teaching hospital, a fully integrated computer data management and medical decision-making system, based on an expansion of the HELP system described in this report. These systems should be designed as teaching and research and development resources, as well as patient care facilitators.

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APPENDIX A

TRAUMA SCORE

DEFINITION

The Trauma Score is a numerical grading system for estimating the severity of injury.[1] The score is composed of the Glasgow Coma Scale (reduced to approximately one third total values) and measurements of cardiopulmonary function. Each parameter is given a number (high for normal and low for impaired function). Severity of injury is estimated by summing the numbers. The lowest score is 1 and the highest score is 16.

Respiratory Rate	10-24/min	4
	24-35/min	3
	36/min or greater	2
	1-9/min	1
	None	0
Respiratory Expansion	Normal	1
	Retractive	0
Systolic Blood Pressure	90 mm Hg or greater	4
	70-89 mm Hg	3
	50-69 mm Hg	2
	0-49 mm Hg	1
	No Pulse	0
Capillary Refill	Normal	2
	Delayed	1
	None	0

Glasgow Coma Scale

Eye Opening	Spontaneous	4
	To Voice	3
	To Pain	2
	None	1
Verbal Response	Oriented	5
	Confused	4
	Inappropriate Words	3
	Incomprehensible Words	2
	None	1
Motor Response	Obeys Command	6
	Localizes Pain	5
	Withdraws (pain)	4
	Flexion (pain)	3
	Extension (pain)	2
	None	1

Total Glasgow Coma Scale Points

13-15 = 5
11-13 = 4
8-10 = 3
5-7 = 2
3-4 = 1

Total Trauma Score 1-16

Trauma Score Operational Definitions

Respiratory Rate
Number of respirations in 15 seconds; multiply by four

Respiratory Expansion
Retractive – use of accessory muscles or intercostal muscle retraction

Systolic Blood Pressure
Systolic cuff pressure; either arm
– auscultate or palpate
No pulse – no carotid pulse

Capillary Refill
Normal – nail bed, forehead, or lip mucosa color refill in 2 seconds or time taken to mentally recite "capillary refill"
Delayed – more than 2 seconds capillary refill
None – no capillary refill

Best Verbal Response
Arouse patient with voice or painful stimulus

Best Motor Response
Response to command or painful stimulus

APPENDIX B

ABBREVIATED INJURY SCALE

Severity Category/Injury Description

Severity code

GENERAL

1. --Aches all over
   --Minor lacerations, contusions, and abrasions (simple closure)
   --All 1° or small 2° or small 3° burns

2. --Extensive contusions; abrasions; large lacerations; avulsions (less than 3" wide)
   --10-20% body surface 2° or 3° burns

3. --Extensive contusions; abrasions; large lacerations involving more than two extremities, or large avulsions (greater than 3" wide)
   --20-30% body surface 2° or 3° burns

4. --Severe lacerations and/or avulsions with dangerous hemorrhage
   --30-50% body surface 2° or 3° burns

5. --Over 50% body surface 2° or 3° burns

HEAD AND NECK

1. --Cerebral injury with headache; dizziness; no loss of consciousness
   --"Whiplash" complaint with no anatomical or radiological evidence
   --Abrasions and contusions of ocular apparatus (lids, conjunctiva, cornea, uveal injuries); vitreous or retinal hemorrhage
   --Fracture and/or dislocations of teeth

2. --Cerebral injury with or without skull fracture, less than 15 minutes unconsciousness; no post-traumatic amnesia
   --Undisplaced skull or facial bone fractures or compound fracture of nose
   --Lacerations of the eye and appendages; retinal detachment
   --Disfiguring lacerations
   --"Whiplash" - severe complaint with anatomical or radiological evidence

3. --Cerebral injury with or without skull fracture, with unconsciousness more than 15 minutes; without severe

neurological signs; brief post-trauma amnesia (less than 3 hours)
--Displaced closed skull fractures without unconsciousness or other signs of intracranial injury
--Loss of eye, or avulsion of optic nerve
--Displaced facial bone fractures or those with antral or orbital involvement
--Cervical spine fractures without cord damage

4. --Cerebral injury with or without skull fracture, with unconsciousness of more than 15 minutes, with definite abnormal neurological signs, post-traumatic amnesia 3-12 hours
--Compound skull fracture

5. --Cerebral injury with or without skull fracture with unconsciousness of more than 24 hours; post-traumatic amnesia more than 12 hours, intracranial hemorrhage; signs of increased intracranial pressure: decreasing state of consciousness, bradycardia under 60, progressive rise in blood pressure, progressive pupil inequality
--Cervical spine injury with quadriplegia
--Major airway obstruction

CHEST

1. --Muscle ache or chestwall stiffness

2. --Simple rib or sternal fracture
--Major contusions of chest wall without hemothorax or pneumothorax or respiratory embarrassment

3. --Multiple rib fractures without respiratory embarrassment
--Hemothorax or pneumothorax
--Rupture of diaphragm
--Lung obstruction

4. --Open chest wounds; flail chests; pneumomediastinum; myocardial contusion without circulatory embarrassment; pericardial injuries

5. --Chest injuries with major respiratory embarrassment (laceration of trachea, hemomediastinum, etc.)
--Aortic laceration
--Myocardial rupture or contusion with circulatory embarrassment

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ABDOMINAL

1. --Muscle ache; seatbelt abrasion, etc.

2. --Major contusion of abdominal wall

3. --Contusion of abdominal organs
--Extraperitoneal bladder rupture
--Retoperitoneal hemorrhage
--Avulsion of ureter
--Laceration of urethra
--Thoracic or lumbar spine fractures without neurological involvement

4. --Minor lacerations of intra-abdominal contents (to include ruptured spleen, kidney, and injuries to tail of pancreas)
--Intraperitoneal bladder rupture
--Avulsion of the genitals
--Thoracic and/or lumbar spine fractures with paraplegia

5. --Rupture, avulsion or severe laceration of intra-abdominal vessels or organs, except kidney, spleen or ureter

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EXTREMITIES AND/OR PELVIC GIRDLE

1. --Minor sprains and fractures and/or dislocations of digits

2. --Compound fractures of digits
--Undisplaced long bone or pelvic fractures
--Major sprains of major digits

3. --Displaced simple long bone fractures, and/or multiple hand and foot fractures
--Single open long bone fractures
--Pelvic fracture with displacement
--Dislocation of major joints
--Multiple amputations of digits
--Lacerations of the major nerves or vessels of extremities

4. --Multiple closed long bone fractures
--Amputation of limbs

5. --Multiple open limb fractures