Tools and Techniques for Enhanced Health Surveillance in Deployed Settings

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ABSTRACT

Historically, diseases and non-battle injuries have had the greatest impact on military mission accomplishment. In recent years, service members and their leaders are increasingly concerned about potential adverse health effects from environmental exposures occurring far from home. Now, there is also an increasing threat of attacks involving weapons of mass destruction. Prompt preventive action is available for many biological threats and would minimize the number of casualties, but this requires early identification of the attack. Enhanced surveillance techniques may hold the key to such early warning systems. This paper describes recent efforts to incorporate this approach as part of in-theater medical operations.

1.0 INTRODUCTION

Historically, diseases and non-battle injuries (DNBI) have had the greatest impact on mission performance. Consequently, the U.S. Department of Defense (DOD) continuously monitors health events in deployed troops, seeking to minimize the adverse effects of DNBI. For many years, military preventive medicine efforts focused on broad categories of endemic communicable diseases and non-battle injuries. As concerns surfaced about unexplained illnesses among Gulf War veterans and of possible disease clusters associated with other military operations, e.g., the possibility of leukemia among Kosovo peacekeeping forces, DoD efforts increased to better integrate occupational and environmental exposure data with health event data. In light of recent attacks in several countries involving chemical and biological agents, there was a clear need to develop or adapt surveillance systems capable of detecting patterns in health-related data that might indicate community exposures to weapons of mass destruction, especially biological agents. The DoD addressed this need by applying enhanced surveillance techniques to the existing DNBI surveillance system.

2.0 FORCE HEALTH PROTECTION

Force Health Protection is an innovative DoD health care strategy that seeks to maximize health and fitness among U.S. service members, prevent casualties, and ensure the best possible care and management of those casualties that cannot be prevented. Key to this strategy is medical surveillance that seeks to identify disease outbreaks (natural or deliberate) at the earliest possible moment. Critical success factors include timely data flow (same day or multiple times a day), accurate and representative data, suitable analytical techniques with interpretation, prompt reporting of the results to the field medics and to decision makers at various levels of command, appropriate actions to prevent or intervene, and ongoing monitoring for the effectiveness of any

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actions taken. This cycle, called deployment health surveillance, is especially difficult to accomplish under field conditions far from home.

3.0 DEPLOYMENT HEALTH SURVEILLANCE

Deployment surveillance has three phases. Predeployment surveillance occurs in the garrison setting and addresses ongoing health assessments, preventive medicine actions (such as immunizations, serum samples for future analysis, blood type determination, etc.), and timely record reviews and personnel questionnaires just prior to departing to the deployed location. Intradeployment surveillance monitors exposures (disease, occupational, environmental, iatrogenic, etc.) and health events that occur while the service member is deployed; this phase of surveillance is the primary focus of this paper. Finally, postdeployment surveillance focuses on health events that occur later in life, after the service member has returned to his/her home station.

3.1 Intradeployment Surveillance Data Sources and Collection Processes

Table 1 lists the primary health event-related data available from the theater. These sources cover a wide variety of health events, but their usefulness remains restricted due to various limitations. Historically, these limitations included difficulty establishing and/or accessing computer networks and connectivity for a mobile population operating in austere, remote sites, non-standardized information management systems for the various military services, ensuring compliance of complete and accurate reporting under physically hazardous conditions (e.g., "under attack"), and the lack of user-friendly electronic data entry systems. Much progress has occurred in these areas, and several promising systems are undergoing testing in the field.

Data Source	Scope	Timeliness	Limitations
Outpatient Records	All services, but variable collection and reporting processes.	Daily to weekly, but variable compliance.	Primarily broad categories of illnesses as opposed to specific diagnoses.
Inpatient Records	All services, but only at sites with inpatient wards.	Not readily available.	Primarily paper-based reporting and locally managed (limited central access).
Air Evacuation	All services, but only cases evacuated using military aircraft.	Data input real-time.	Severity biased. Causal information lacking.
Mortality Reports	Full autopsy and investigation of all deaths.	Days to weeks.	Severity biased.
Safety Reports	Only cases meeting pre-defined "accident" criteria. Often have extensive information about circumstances and causes.	Days to weeks to months.	Not a medical reporting system. Limited releasability for confidentiality.

Table 1: In-theater Deployment Surveillance Data Sources

3.2 Disease, Non-battle Injury (DNBI) Surveillance Categories

Initial deployment surveillance efforts focused on broad disease and injury categories (see Table 2), primarily because most deployed units had limited access to computers. Using broad categories allowed the deployed

medics to track local health events using paper logs and assigning each visit to the category they thought best based on definitions provided by the U.S. Joint Chiefs of Staff. The system started in the late-1990s and required deployed medical units to send weekly reports to a stateside analysis hub. Such an approach has been very useful from a general preventive medicine standpoint, helping to identify areas needing investigation or special, focused preventive measures. However, it was clear that this approach could not identify possible attacks involving weapons of mass destruction since the categories were so broad (unusual diagnoses would get lost in the "noise" of common events, like upper respiratory illnesses) and the data was 10-14 days old by the time it reached the central analysis hub. Consequently, a decision was made to apply enhanced surveillance techniques, primarily by redefining several categories in a more focused manner and requiring daily reporting instead of weekly.

JCS Deployment Surveillance Category	Examples
Combat/Operational Stress Reactions	Acute debilitating mental, behavioral, or somatic symptoms not explained by physical disease or injury.
Dermatological	Heat rash, acne, fungal, cellulitis, blisters, sunburn
Gastrointestinal, Infectious	Diarrhea, nausea & vomiting, hepatitis (not ulcers)
Gynecological	Menstrual irregularity, vaginitis (not pregnancy)
Heat/Cold Injuries	Hypothermia, frostbite, trench foot, heat stroke
Injuries, Recreational/Sports	Injuries from informal pursuit of personal or unit fitness
Injuries, Motor Vehicle Accidents	Direct consequence of motorized vehicular accidents
Injury, Work/Training	On-the-job injuries or formal unit physical fitness training
Injury, Other	All other injuries not included in above categories
Ophthalmologic	Conjunctivitis, foreign body, corneal abrasion, iritis
Psychiatric, Mental Disorders	All except combat/operational stress reactions
Respiratory	Bronchitis, pneumonia, asthma, sinusitis, otitis, flu, upper respiratory illness (cold)
Sexually Transmitted Diseases	All sexually transmitted infections (chlamydia, HIV, etc.)
Fever, Unexplained	Temperature $\geq$100.5, at least 24 hours, diagnosis unclear
All Other, Medical/Surgical	Any other initial visit not encompassed above
Dental	Any disease of the teeth, gums, and/or oral cavity
Miscellaneous/Administrative/Follow-up	Pregnancy, immunizations, medicine refills, routine physical exams, e.g., visual or hearing screening

Table 2: Deployment Health Surveillance DNBI Categories and Examples

3.3 Enhanced DNBI Surveillance Using Special Surveillance Categories

A group of epidemiologists and preventive medicine specialists established five special surveillance categories that attempt to capture health events most likely to be associated with known chemical or biological warfare threats.

Category	Definition	Threat
Systemic Fever	Unexplained temp > 38C (100.5F) for 24 hours, or a history of chills and fever without a clear diagnosis. Includes flu-like illnesses, with fever and multiple systemic complaints (including cough).	Generic biological agents with ill-defined flu-like illness, e.g., tularemia.
Lower Respiratory Illness	Bronchitis, pneumonia, new onset reactive airway disease, pleurisy, or respiratory difficulty of unclear etiology.	Primarily anthrax, maybe mustard agents.
Infectious GI	Any infection, usually manifest by vomiting and/or diarrhea.	Multi-purpose, but primarily to identify food-related illnesses (could indicate contamination, tampering, or side effects of biological agents, e.g., ricin.
Dermatologic, Unclear Cause	Skin infections, blisters, ulcers, etc.	Smallpox, chemical blister agents.
Unexplained Neuro	Cases of altered consciousness, cranial nerve dysfunction, muscle weakness.	Botulinum toxin.

Table 3: Deployment Health Surveillance Special Categories

3.4 Statistical Analysis and Reporting

Analyzing deployed health event data presents several challenges. Reporting is often erratic as military units move from place to place, interrupting data flow for varying periods of time. Accurate population denominator data is hard to get, so there must be methods for dealing with event counts when accurate rate calculations aren't possible. Health event data of this type, especially in a young population specifically screened for peak health and fitness, are relatively rare events and not normally distributed. Finally, good comparison data are rarely available as local health departments may not have the level of data desired or may not be willing to provide the data. Using rates from other countries or from the unit's garrison setting may well mislead the analyst as the environmental conditions, levels of endemic disease, and other unique factors likely differ significantly from place to place. Past analysis of deployment health surveillance data from two military sites 20 km apart showed substantially different disease rates despite apparently similar populations, weather conditions, surrounding industrial exposures, etc. The best approach is to determine site- and population-specific comparison rates at the earliest possible time. Based on these requirements, the decision was to modify the graphs of current/past experience[1] employed by the Centers for Disease Control and Prevention with reporting of significant national medical event patterns.

3.4.1 Current/Past Experience Graphs (CPEG)

The CPEG approach compares the number of reported cases (or rates) for a specified time period (day, week, month, year) and compares it with historical data (e.g., over the previous month, compared to the same period of time in each of the last five years, etc.). The analytical method uses the 'z-score' derived from the normal approximation of the exact Poisson calculation for rare events. This method has the advantage of standardizing the scale, which allows data for various outcomes (health events), locations, and periods of time to be graphed together.

$$p - value = \frac{e^{-\lambda} \cdot \lambda^{x}}{x!} \qquad z\text{-}score \cong \frac{\sqrt{obs} - \sqrt{exp}}{\frac{1}{2}}$$

Exact Poisson calculation **Normal approximation**

Obs=observed value, Exp=expected value

Figure 1: Statistical Equations for Poisson and Z-score Calculations

The normal approximation[2] is simpler than the exact calculation and has the added advantage of being easy to calculate using standard Microsoft® software applications like Excel® and Access® that are more readily available in deployed settings and eliminates the need for expensive advanced statistical software packages. The normal approximation is sound when sample sizes are large. If the population (denominator) fluctuates by more than 20% during the identified time period, expected counts can be adjusted to reflect the difference. Figure 2 is a sample CPEG. It is graphically dense, summarizing large volumes of information on a single, easy to read, slide. Increases and decreases from the expected baseline are readily apparent with red indicating excursions significant at the 0.01 level while green indicates values within the expected historical range. This tool is specifically designed to be highly sensitive. A high proportion of false positives is acceptable given the disastrous potential outcome of missing a serious disease outbreak or attack. A side effect of this sensitivity is that gradual changes in the event counts or rates will not trigger a threshold violation. A single statistical analysis is not enough. An industrial process control approach fills this gap.

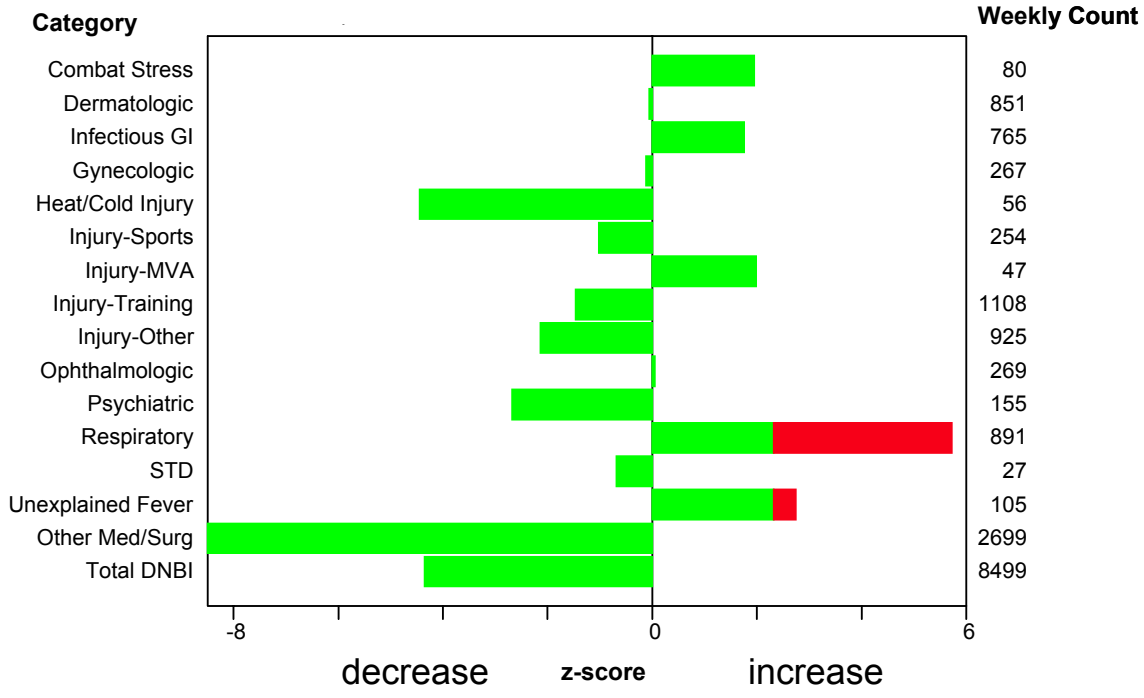

Figure 2: Presenting Data Using a Current/Past Experience Graph

3.4.2 Process Control Graphs

Figure 3 illustrates a process control method for documenting variations from a mean over a specified time period, six months in this case. There are two threshold levels depicted. These thresholds are sometimes referred to as upper control limits in quality control literature. One is an intermediate alert level (yellow line) established as two standard deviations (S.D.) above the six-month mean while the other is a higher level alarm (red line) established at three standard deviations above the mean. Though lower control limits are also used in manufacturing (e.g., assembly line) control process analyses, there is little utility to including them in health event analyses where decreases in health events are almost always beneficial. The desire to identify outbreaks at the earliest opportunity must be tempered by limited resources. Public health investigations divert staff from other duties, so rather than immediately responding to every excursion above an alert or threshold line, the following tiered approach is used to determine when to request a focused investigation:

- Any time the count or rate exceeds the red alarm level (i.e., >3 S.D.)
- When two out of three consecutive data points exceed the yellow alarm level (i.e., >2 S.D.)
- When five out of six consecutive data points exceed the 6-month mean

The example in Figure 3 shows two of these conditions, one alarm in the first week of May and one alert in the first week of July. Seeing six months of results at a glance also makes it easier to follow seasonal trends and other long-term variations.

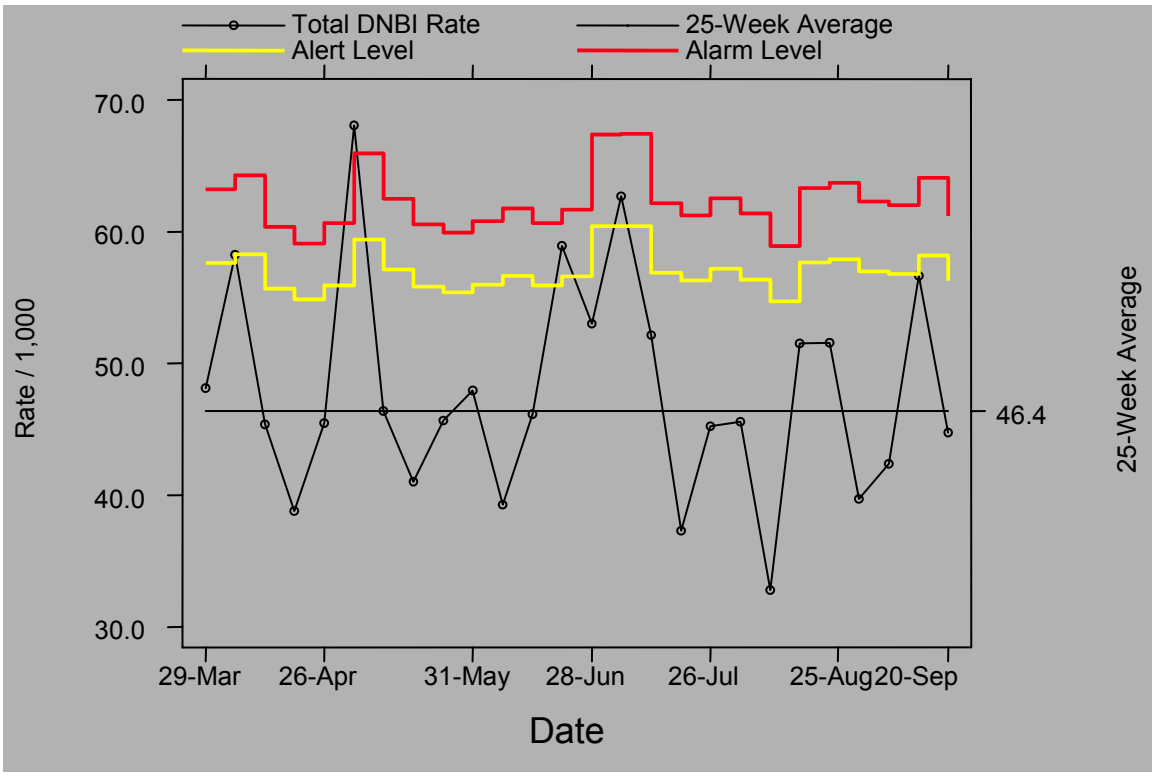

Figure 3: Example Process Control Graph

3.4.3 Final Analysis, Interpretation, and Distribution

Using the CPEG and the process control graphs together provides a more complete picture. Figure 4 is an example of such a paired output. Unit 322 on the CPEG shows a red bar indicating a small, but statistically significant increase in febrile respiratory illnesses (FRI) for the week of 14 March 2003 compared to the previous four weeks. However, the process control chart provides some reassurance in that the 14 March rate is actually below the two standard deviation alert level. Consequently, the on-site public health staff may reasonably choose to postpone any aggressive investigation and continue to follow the results the next few days to see if there is a continuing upward trend. In cases where the remote analysts are unsure of the significance, they contact the field medical staff to ensure that they are aware of the situation and ask them to provide additional information based on their local evaluation. These comments are then added below the graphs and combined into a report available for review on a classified Internet site. The final reports often include site-specific graphs as well as aggregate reports on a regional, operational, or component service level.

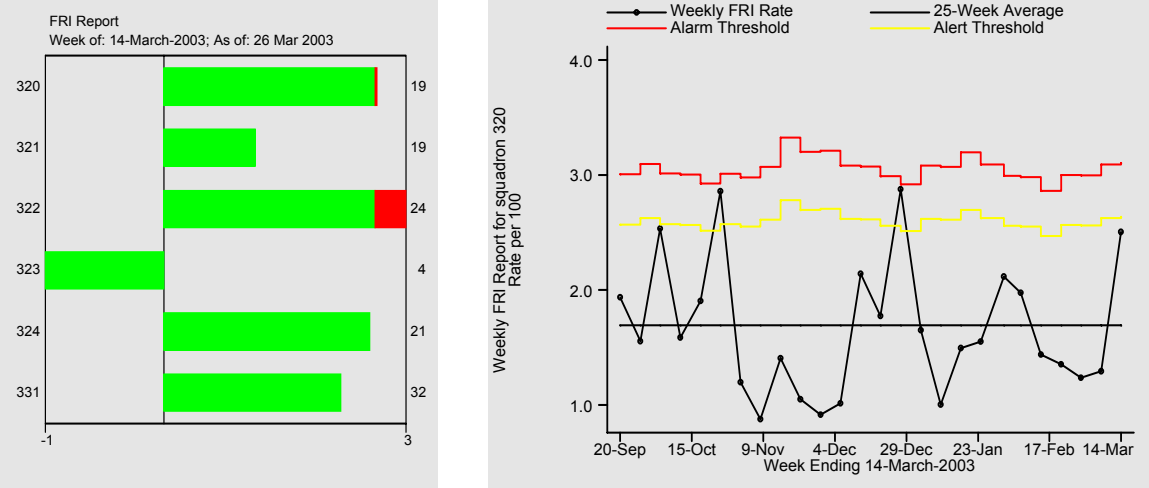

Figure 4: Complementary Use of CPEG and Process Control Charts

4.0 FUTURE DIRECTIONS

This paper focuses on deployed health event surveillance, especially as one method to help identify unrecognized attacks involving weapons of mass destruction. The described methods hold promise, but there remain a number of limitations and a need to validate and compare these techniques with other methods, especially in regard to possible long-term health outcomes related to exposures occurring during deployed military operations. Some areas to address include:

- Data gaps
  - Important data categories remain difficult to obtain, such as comprehensive battle injury data; centralized electronic data for inpatient care occurring in-theater, e.g., hospitalizations and surgeries, access to electronic laboratory data including the emerging field versions of various rapid screening tests (PCR, microarrays, various biomarkers), etc.
  - Lack of coding for causal/situational factors in injuries, accidents, and fatalities
  - Long-term outcome registries for reproductive health, cancer, etc.
  - Timely environmental and occupational exposure data
  - Accurate geospatial location data for both individuals and exposures (e.g., plumes)
- Dealing with data overload
  - Adapting artificial intelligence and/or neural nets to help parcel large data streams into manageable portions for human analysts to interpret while balancing sensitivity and specificity
  - Integrating diverse data streams, e.g., exposure data with health outcomes
- Standardization of data collection, analysis, and reporting processes across the DoD
  - Validating and refining statistical methods, disease category mappings, alarm threshold levels, etc.

5.0 CONCLUSIONS

The U.S. Department of Defense has made significant progress in establishing health screening and surveillance systems to cover a service member's entire military career, and even after the individual leaves military service. More and more electronic data are becoming available, but more is not necessarily better. Inconsistent and incomplete data capture, human errors (e.g., inaccurate coding) and other limitations complicate interpretation. It remains critical to validate the many proposed health surveillance methodologies in order to identify those data sets and statistical approaches that will provide the best value. Ongoing health surveillance is one of the key pillars of Force Health Protection and will help the U.S. meet its heartfelt obligation to protect the health of American military service members, their families, and the communities with which they interact around the world.

REFERENCES:

[1] Stroup DF, Wharton M, Kafadar K, Dean AG. Evaluation of a method for detecting aberrations in public health surveillance data. Am J Epidemiol 1993;137(3):373-80.

[2] Hirsch RP, Riegelman RL. Statistical First Aid. Interpretation of Health Research Data. 1992. Boston; Blackwell Scientific Publications.

SYMPOSIA DISCUSSION - PAPER 28

Authors Name: Col Cox (US)

Discussor's Name: Prof. Dr von Restorff (GE)

Question:
Do you collect environmental data at the same time?

By environmental I mean weather etc and activity because both may influence health.

Author's Reply:
U.S. DoD does collect extensive occupational and environmental exposure data, including meteorological data. A central archive exits, but data flow is not completely established across the military services. Once the system is functioning, we will begin to review health events, both acute and long-term, against known environmental exposures to see if there are unrecognized relationships.

Authors Name: Col Cox (US)

Discussor's Name: Surg.Capt Hoejenbos (NL)

Question:
1) How can it be prevented that people are counted twice or more?
2) Are other personnel than military in the system?

Author's Reply:
1) Guidelines tell medics to report initial visits in the respective categories. There is a separate category for follow-up visits. Errors do occur. Planned electronic data collection systems will help eliminate these mistakes.
2) The deployed health surveillance system only applies to active field operations. It captures data from all people presenting for care at the deployed medical treatment facility, including allied/coalition members and deployed U.S. civilians or contractors. Similar, standardized surveillance systems will apply to the in-garrison (home-front) setting.